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FINAL REPORT

APOLLO  
LUNAR ORBITAL  
SCIENCES PROGRAM  
ALPHA AND X-RAY  
SPECTROMETERS

CONTRACT NOS.  
NAS9-9982 AND NAS9-9983

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PREPARED FOR:  
NATIONAL AERONAUTICS  
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MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS 77058

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Final Report for

Contracts NAS9-9982 and NAS9-9983

APOLLO LUNAR ORBITAL SCIENCES PROGRAM

ALPHA AND X-RAY SPECTROMETERS

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7 August 1972

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## 1.0 INTRODUCTION

This Final Report on the Alpha and X-Ray Spectrometers is submitted as required under Article XV, Item B, of the subject contracts, as modified by NASA/MSC letter BC341/L798-71/L90 dated 9 November 1971. Since the two contracts result in one integrated system comprising an Alpha Particle Spectrometer and an X-Ray Spectrometer, this report combines the description of activities and deliverable items of the two contracts.

This Final Report will detail the accomplishments of the Apollo Lunar Spectrometer Program and the management controls instituted that resulted in the successful flights of Apollo XV and Apollo XVI. It is worthwhile to note here that with all the problems associated with the Apollo Lunar Orbital Science Program, both technical and financial, the AS&E Spectrometers were the first major experiment on Apollo XV and Apollo XVI to be delivered to KSC. They were the first experiments to be qualified for space flight worthiness and they were the first experiments to be certified flight worthy.

During the flight on Apollo XV, the two AS&E Spectrometers performed remarkably well, averaging over 90% efficiency. Their performance on the Apollo XVI flight was even better.

From a scientific viewpoint, the X-Ray Spectrometer did exhibit a noise problem that inhibited somewhat the detection of lower energy levels; however, it is the estimate of the AS&E scientific personnel that the X-Ray experiment performed at about 90% of perfection. The X-Ray noise problem has been identified and corrected so it is safe to assume that the performance of the X-Ray Spectrometer on Apollo XVI will be even better than the performance of the Spectrometer on Apollo XV.

The Alpha-Particle Spectrometer on the Apollo XV experiment had two detectors that were noisy approximately 40-50% of the time.

With ten detectors on board, it is then shown that between 90 and 92% of the data available was retrieved and is available for analysis.

A side point of the Apollo XV flight was the use of the X-Ray Spectrometer, in conjunction with the Crimean Observatory of the U. S. S. R. , the Wise Observatory in Israel, and the Westerbork Observatory in the Netherlands to observe the two X-Ray sources Scorpio X-1 and Cygnus X-1. This was accomplished during the flight of Apollo XV by holding the space craft in a "barbecue mode" and pointing the X-Ray Spectrometer at these two sources.

The two powerful x-ray sources observed by Apollo XV, Scorpio X-1 and Cygnus X-1, can also be seen on the earth in other regions of the electromagnetic spectrum. Sco X-1 is detectable in both visible light and radio emission and Cyg X-1 in radio. We know that the visible light and radio emissions are also variable, but we do not yet know how the light or radio variability correlates with the x-ray variability. Particular models for these x-ray objects make rather specific predictions concerning the relation of x-ray and other variability ranging from no correlation to complete correlation. Consequently, in order to broaden the scope of the investigation, arrangements were made for ground based observations to monitor the visible and radio emission simultaneously with Apollo XV. The Apollo observations were made during Houston daylight hours which is not a favorable situation for observatories in North America. Fortunately, observatories located at more easterly points where it was night were able to acquire Sco X-1 and Cyg X-1 simultaneously with Apollo XV. The optical flux from Sco X-1 was observed by the Crimean Astrophysical Observatory in the U. S. S. R. with a time resolution of 20 seconds and the Wise Observatory in Israel

with a time resolution of 4 minutes. Radio emission from Sco X-1 and Cyg X-1 was observed by the Westerbork Observatory in the Netherlands.

The results of this experiment will be analyzed in part under the contract change notice #27 to the NAS9-9983 contract. Similar work was performed during the flight of Apollo XVI and will be analyzed in part under the contract change notice #31 to the NAS9-9983 contract.

## 2.0 LUNAR PROGRAM MANAGEMENT

### 2.1 Lunar Contract

#### 2.1.1 Contract Value

At the present time (through MOD 30S) the contract value on the Alpha-Particle Spectrometer Experiment (NAS9-9982) is \$2,005,854- of cost with a fixed fee of \$86,364- for a total cost plus fixed fee of \$2,092,218-. Funding limitation on the Alpha-Particle Experiment (NAS9-9982), through Contract MOD 30S is \$2,230,000-. An historical contract value and funding summary by contract modification is shown on Table II-1.

The estimated cost-at-completion as detailed on the 533 financial management reporting form, submitted for the period ending 28 June 1972 is \$2,298,118- of which \$2,092,218- represents negotiated cost and fixed fee and an estimated \$205,900- for overrun.

At the present time (through MOD 36S), the contract value on the X-Ray Spectrometer Experiment (NAS9-9983) is \$5,258,109- of cost with a fixed fee of \$268,907- for a total cost plus fixed fee of \$5,527,016-. Funding limitation on the X-Ray Spectrometer Experiment (NAS9-9983) through contract MOD 36S is \$6,470,000-. An historical contract value and funding summary is shown on Table II-2.

Alpha-Particle Spectrometer  
 Contract Value Summary  
 NAS9-9982

<u>MOD</u>	<u>Function</u>	<u>Cost</u>	<u>Fee</u>	<u>Total</u>
	Original Contract Value	817,756-	57,100-	874,856-
1S	Funding	392,588-	27,412-	420,000-
2S	Funding	140,210-	9,790-	150,000-
3S	Funding	163,578-	11,422-	175,000-
4S	Funding	121,380-	8,476-	129,856-
5C	Provisional Funding	95,144-	-0-	95,144-
6C	Provisional Funding	45,000-	-0-	45,000-
7C	Provisional Funding	95,000	-0-	95,000-
8C	Provisional Funding	105,000-	-0-	105,000-
9C	Correct Typø Error			
10S	Extend Stop Work Order			
11C	Provisional Funding	235,000-	-0-	235,000-
12S	Extend Stop Work Order			
13C	Provisional Funding	115,000-	-0-	115,000-
14S	Increase Contract Value	1,543,334-	57,100-	1,600,434-
14S	Provisional /Partial Funding	57,100-	-0-	57,100-
15S	Provisional/Partial Funding	50,000	-0-	50,000-
16S	Provisional/Partial Funding	181,600-	-0-	181,600-
17S	Provisional Funding	78,400-	-0-	78,400-
18S	Provisional Funding	25,000-	-0-	25,000-
19S	Revise Article XXV			
20C	Provisional Funding	115,000-	-0-	115,000-
21S	Increase Contract Value	1,628,334-	62,850-	1,691,184-
22C	Provisional Funding	35,000-	-0-	35,000-
23S	Increase Contract Value	1,791,397-	74,235-	1,865,632-
24S	Provisional Funding	25,000-	-0-	25,000-
25C	Provisional Funding	25,000-	-0-	25,000-
26C	Provisional Funding	25,000-	-0-	25,000-
27S	Increase Contract Value	1,932,257-	83,174-	2,042,257-
28C	Partial Funding	35,000-	-0-	35,000-
29S	Increase Contract Value	2,000,352-	86,006-	2,086,358-
30S	Increase Contract Value	2,005,854-	86,364-	2,092,218-
	Funding	70,000-	-0-	70,000-

Table II-1

X-ray Spectrometer  
Contract Value Summary  
NAS9-9983

<u>MOD</u>	<u>Function</u>	<u>Cost</u>	<u>Fee</u>	<u>Total</u>
	Original Contract Value	2,329,744-	162,000-	2,491,744-
	Original Funding	654,490-	45,510-	700,000-
1S	Funding	691,889-	48,111-	740,000-
2S	Funding	280,495-	19,505-	300,000-
3S	Funding	182,322-	12,678-	195,000-
4S	Funding	416,068-	28,932-	445,000-
5S	Funding	104,480-	7,264-	111,744-
6C	Provisional Funding	18,256-	-0-	18,256-
7C	Provisional Funding	270,000-	-0-	270,000-
8C	Provisional Funding	340,000-	-0-	340,000-
9S	Extend Stop Work Order			
10C	Provisional Funding	580,000-	-0-	580,000-
11S	Extend Stop Work Order			
12C	Provisional Funding	305,000-	-0-	305,000-
13S	Increase Contract Value	3,780,940-	171,170-	3,952,110-
13S	Provisional Funding	52,890-	-0-	52,890-
14S	Provisional Funding	475,000-	-0-	475,000-
15S	Increase Contract Value	3,837,942-	175,134-	4,013,076-
16S	Provisional/Partial Funding	180,000-	-0-	180,000-
17S	Partial Funding	20,000-	-0-	20,000-
18S	Provisional/Partial Funding	481,500-	-0-	481,500-
19S	Provisional Funding	183,500-	-0-	183,500-
20S	Provisional Funding	200,000-	-0-	200,000-
21S	Provisional/Partial Funding	225,000-	-0-	225,000-
22S	Revise Article XXV			
23C	Provisional/Partial Funding	145,000-	-0-	145,000-
24S	Increase Contract Value	3,929,942-	181,384-	4,111,326-
24S	Provisional Funding	20,000-	-0-	20,000-
25C	Provisional/Partial Funding	76,500-	-0-	76,500-
26C	Provisional Funding	53,500-	-0-	53,500-

Table II-2

27S	Increase Contract	4,555,942-	224,909-	4,780,851-
28S	Provisional Funding	105,000-	-0-	105,000-
29C	Provisional Funding	130,000-	-0-	130,000-
30S	Provisional Funding	50,000-	-0-	50,000-
31S	Increase Contract Value	4,947,942-	250,389-	5,198,331-
32S	Increase Contract Value	5,048,838-	254,689-	5,303,527-
33C	Partial Funding	70,000-	-0-	70,000-
34S	Increase Contract Value	5,201,838-	265,039-	5,466,877-
35S	Increase Contract Value	5,248,157-	268,260-	5,516,417-
36S	Increase Contract Value	5,258,109-	268,907-	5,527,016-
	Partial Funding	50,000-	-0-	50,000-

Table II-2 (concluded)

The estimated cost-at-completion as detailed on the 533 financial management reporting form, submitted for the period ending 28 June 1972, is \$6,484,716- of which \$5,527,016- represents negotiated cost plus fixed fee.

### 2.1.2 Contract Modifications

Tables II-3 and II-4 show a historical summary to date of all contract modifications to the NAS 9-9982 and NAS9-9983 contract.

## 2.2 Organization

### 2.2.1 Introduction

As directed by NASA/MSC (TWX EF-70-T50) on 11 March 1970, AS&E implemented a program plan whose scope and effort were far beyond that originally anticipated or in effect at that time.

The Apollo Lunar X-ray and Alpha Spectrometers Program Plan proposes the controls, plans, and procedures to be used on the Spectrometers Program. The work breakdown structure in Section 2.2.2 functionally divides the total work to be accomplished on the program into logical elements easily assigned to the various skill centers within AS&E.

The work to be accomplished within each work package is defined in Section 2.2.3.

CONTRACT CHANGE NOTICES  
NAS9-9982

<u>CCN</u>	<u>DESCRIPTION</u>	<u>DATE</u>	<u>RESPONSE</u>	<u>NEGOTIATED</u>
1	P&I Specification (12SEP69)	11-19-69	Ltr, 24NOV69	1SEP70
2	Swap Qual & Flt #2	2-13-70	None	1SEP70
3	P&I Specification (22DEC69)	6-25-70	ASE-2429A	22JUN71
4	Delete Alpha Standby Switch	6-25-70	ECP #5	22JUN71
5	New Timing Signal	3-24-70	ASE-2415	22JUN71
6	Delete Conformal Coating	10-9-70	ECP #6	22JUN71
7	Revision to EIS	10-9-70	ECP #7	22JUN71
8	KSC Test Procedure Meeting	10-26-70	ECP #16	22JUN71
9	Mass Mockup Retrofit	11-13-70	ETP-L876	22JUN71
10	Change SPA Weight Limit	12-2-70	ECP #8	22JUN71
11	Change Spectral Range & Power Limits	12-2-70	ECP #9	22JUN71
12	BTE Simulator Fabrication	12-9-70	ECP #12	22JUN71
13	KSC Field Support	1-14-71	ASE-2847	29FEB72
14	520 Spares Program	1-27-71	ECP #14A	22JUN71
15	EMI Filter Fix	1-27-71	ECP #17 (to X-Ray)	22JUN71
16	Retrofit of Flt #1	2-3-71	ECP #18	26OCT71
17	Incorporate IRN 8194	2-26-71	None	22JUN71
18	Amend P&I Spec by SCN's	2-24-71	ECP #4	22JUN71
19	Shock Isolation Retrofit	2-24-71	None	22JUN71
20	SPA Thermal Protection	3-16-71	ECP #21A	26OCT71
21	IOU Capacitor Addition	4-5-71	ECP #20	22JUN71
22	NR SIM Door Support	4-14-71	ECP #15	22JUN71
23	Sustaining Engineering	5-17-71	ASE-2848	29FEB72
24	Mark Solar Monitor Connectors	6-4-71	ASE-2856	29FEB72
25	Mission Support at MSC (Apollo 15)	6-27-71	(included in ASE-2848)	29FEB72
26	Assorted Small Changes	8-19-71	ASE-2857	29FEB72
27	Repair Detector Module (S/N 7367)	9-7-71	ASE-2854	29FEB72

CONTRACT CHANGE NOTICES  
NAS 9-9983

<u>CCN</u>	<u>DESCRIPTION</u>	<u>DATE</u>	<u>RESPONSE</u>	<u>NEGOTIATED</u>
1	P&I Specification (12SEP69)	11-4-69	Ltr, 24NOV69	1SEP70
2	Hi-Fi Mockup	12-5-69	ETP-L634	1SEP70
3	Swap Qual & Flt #2	2-13-70		1SEP70
4	(Cancelled)			
5	New Timing Signal	3-24-70	ASE-2415	22JUN71
6	P&I Specification (22DEC69)	6-25-70	ASE-2429A	22JUN71
7	Change SPA EIS	10-9-70	ECP #7	22JUN71
8	KSC Test Procedure Meeting	10-26-70	ECP #16	22JUN71
9	Mass Mockup Retrofit	11-13-70	ETP-L876	22JUN71
10	Change SPA Weight Limit	12-7-70	ECP #8	22JUN71
11	Change Spectral Range & Power Limits	12-2-70	ECP #9	22JUN71
12	BTE Simulator Fab	12-9-70	ECP #12	22JUN71
13	KSC Field Support	1-14-71	ASE-2847	29FEB72
14	EMI Filter Fix	1-27-71	ECP #17	22JUN71
15	(Part of CCN #20)		N/A	N/A
16	Retrofit of Flt #1	2-3-71	ECP #18	26OCT71
17	Incorporate IRN 8194	2-26-71	None	22JUN71
18	Amend P&I Spec by SCN's	2-24-71	ECP #4	22JUN71
19	Shock Isolation Retrofit	2-24-71	None	22JUN71
20	SPA Thermal Protection	3-16-71	ECP #21A	26OCT71
21	IOU Capacitor Addition	4-5-71	ECP #20	22JUN71
22	NR SIM Door Support	4-14-71	ECP #15	22JUN71
23	Sustaining Engineering	5-17-71	ASE-2848	29FEB72
24	Mark Solar Monitor Connectors	6-4-71	ASE-2856	29FEB72
25	Mission Support at MSC (Apollo 15)	6-27-71	(included in ASE-2848)	29FEB72
26	Assorted Small Changes	8-19-71	ASE-2857	29FEB72
27	Preliminary Analysis of Galactic X-Ray Sources (Apollo 15)	8-19-71	ASE-2791	29FEB72
28	False X-Ray Data Output Fix	10-7-71	ASE-2858	29FEB72
29	Solar Monitor Filter	10-7-71	ASE-2859	29FEB72
30	Spare Radioactive Sources	11-17-71	ASE-2860	29FEB72
31	Apollo 16 Galactic X-Ray Program	1-26-72	ASE-2925	26APR72

### 2.2.2 Work Breakdown Structure for the Program

The Apollo Lunar X-ray and Alpha Spectrometers Program is composed of the design, development, fabrication, and test of an instrumentation system and its ground support equipment. This instrumentation system, shown in Figure 2-1, is composed of an X-ray Sensor Assembly and Processor Assembly, and an Alpha Sensor Assembly and Processor Assembly housed in an integrating structure. A separate component of the X-ray Spectrometer is the Solar Monitor Assembly. These spectrometers have been assigned to fly in Apollo 15 and 16 in Bay I of the CSM. AS&E is presently under contract to provide this instrumentation along with its ground support equipment. The work breakdown structure (WBS) for this effort is shown in Figure 2-2. Each work package within the work breakdown structure is composed of a number of tasks.

The work breakdown structure is a functionally oriented family-tree division of hardware, software, and services which defines and graphically displays the end products to be produced as well as the work to be accomplished in order to achieve program objectives.

The work breakdown structure is a framework for planning and controlling program cost, schedule, and technical performance at any desired level of the structure. The subdivisions of work identified are manageable units that can be clearly defined, easily related to significant milestone objectives, and effectively estimated and statused. In tracking costs, it is possible to show accumulated charges against any given functional element in the WBS, thereby permitting identification of cost to statement of work elements, and further identifiable to per cent of task completion.

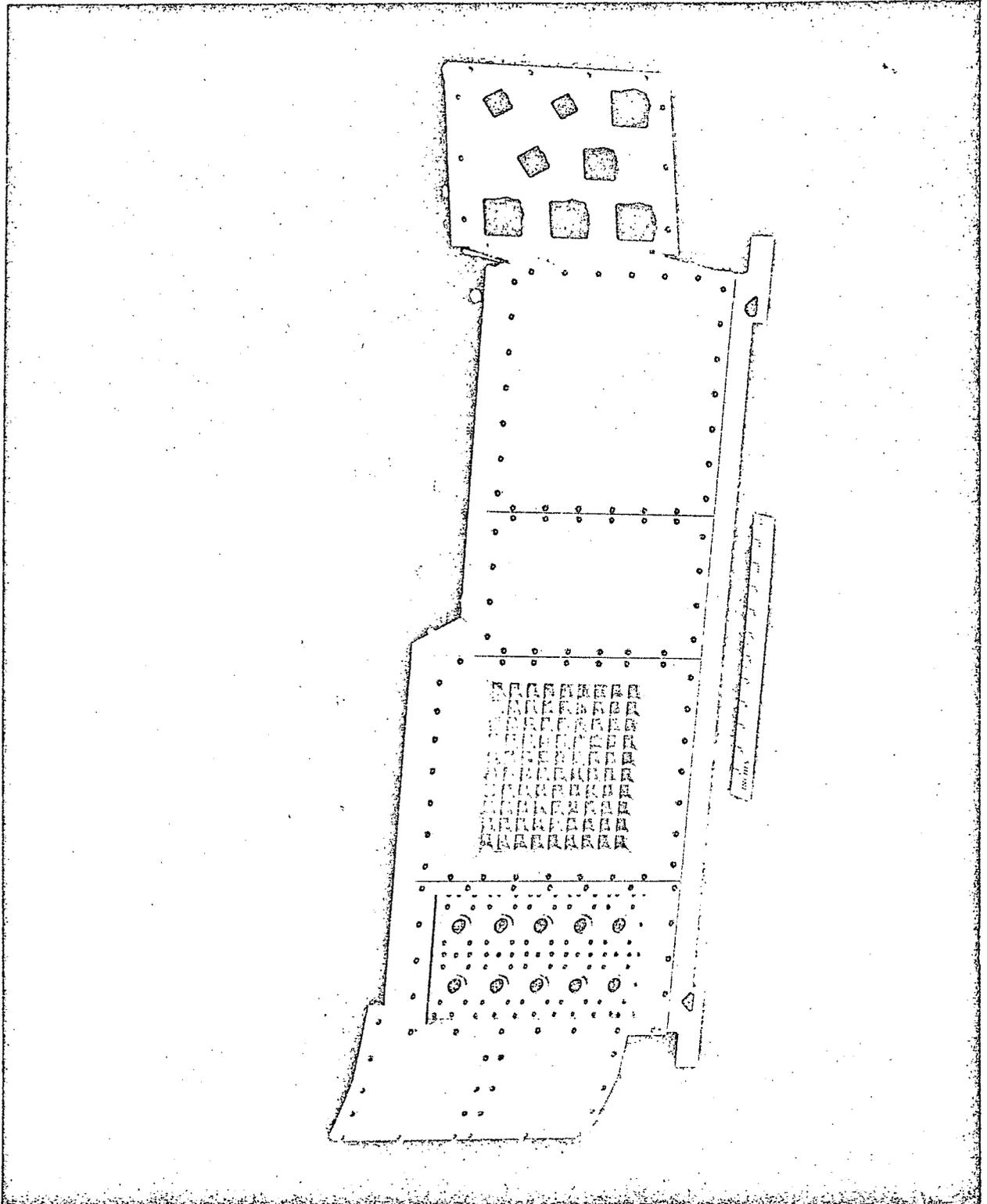


Figure 2-1. Instrumentation System

EJ-019

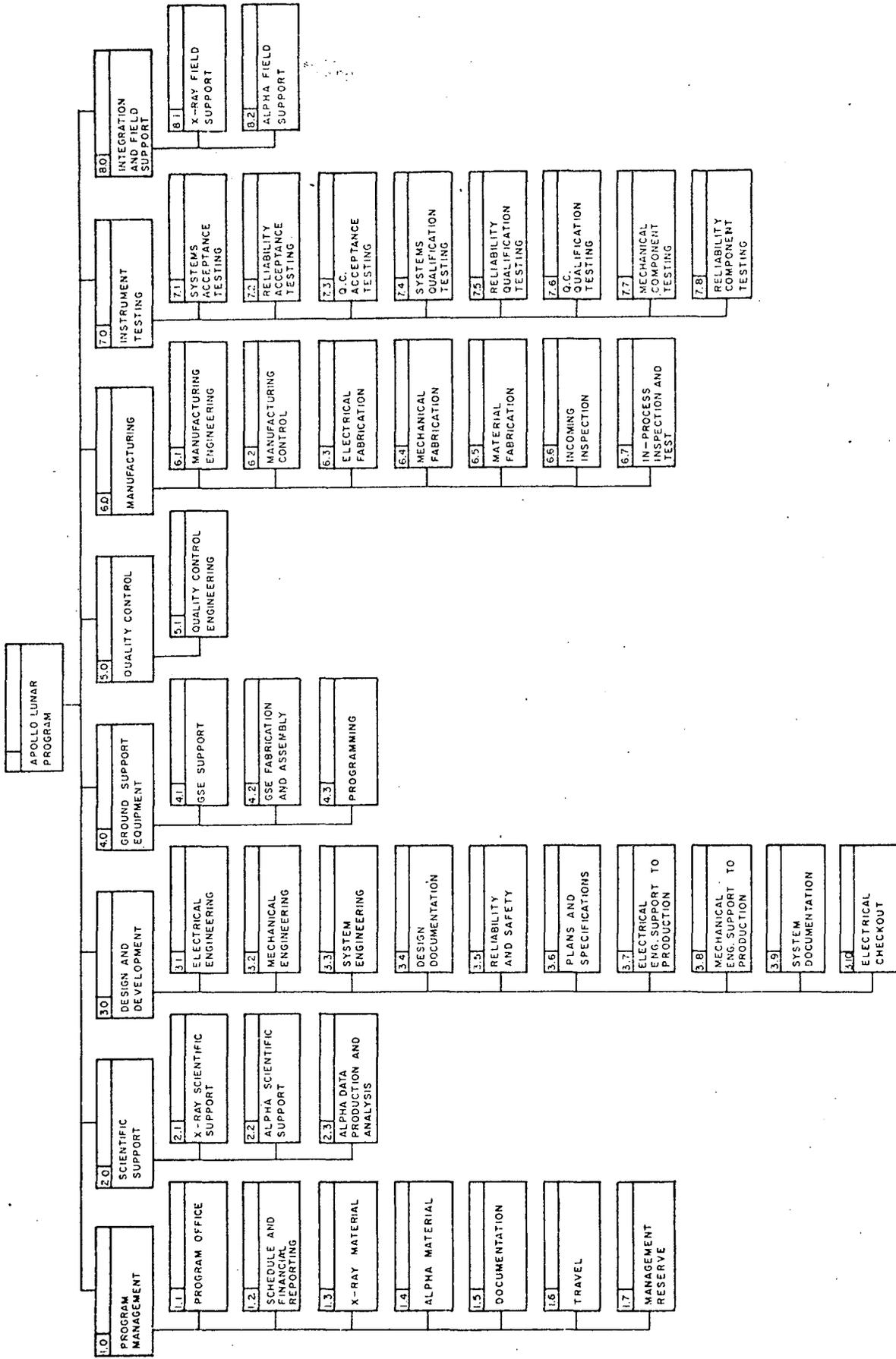


Figure 2-2. Work Breakdown Structure

Responsibility for the tasks defined in the work packages is assigned to one person, designated as the Work Package Manager, who is held accountable for the satisfactory completion of those efforts within stipulated cost and schedule parameters.

Work is authorized to each Work Package Manager by release of an Account Distribution Number (ADN). This document is approved by the Program Manager and controlled by the Program Administrator in the Program Office.

The WBS for Apollo Lunar serves as the means for linking diverse elements such as the hardware, software, services, cost and schedule into a common framework. This common framework, against which all program elements may be evaluated and controlled, results in an efficient system of program control and an increased awareness of the scope of system and functional activities.

#### Program Management (1.0)

Program Management consists of the program office which is responsible for the management of the program. Included in program management are customer interface, subcontractor management, technical direction and interface, and financial and schedule control.

#### Scientific Direction and Support (2.0)

This work package provides scientific direction and support to all other phases of the program to ensure that no operation comprises the stated scientific objectives of the instruments. This task includes the planning for data handling and the interfacing with the designated Principle Investigators. It also includes the separation of the data handling programs for the Alpha Spectrometer.

#### Design and Development (3.0)

The work package includes the accomplishment of a completely

detailed design sufficient for production and test of the required instruments. This work package covers all reliability effort and the direction of the safety program. Included also is the configuration control program, the preparation of contract documentation, support-to-production, drafting, and production testing.

#### Ground Support Equipment (4.0)

This package includes all the activity necessary to obtain the required GSE that will interface with the scientific instrumentation at the various test stations designated in the checkout flow plans. Included in this is the necessary software programming.

#### Quality Control (5.0)

Quality Control includes those activities that ensure the quality levels imposed by the contract are achieved in the end items.

#### Manufacturing (6.0)

Manufacturing covers all tasks necessary to fabricate and assemble the hardware required by the contract. Included in this activity are the material and production control functions, and inspections.

#### Instrument Testing (7.0)

This task consists of the component testing and evaluation, and program acceptance testing and qualification testing.

#### Field Support (8.0)

This effort is composed of the necessary operations both in-house and at the various field facilities that ensure an adequate level of instrument support at these locations is always available.

### 2.2.3 Task Descriptions

The task descriptions in this section are the narratives included in each task package that describe the work to be accomplished. These task descriptions are an element of each task package.

### Program Management (1.0)

Management of the Apollo Lunar X-ray and Alpha Spectrometer Program will be implemented by the Apollo Lunar Program Office. The Program Manager who directs the activity of this office has full responsibility and authority for the accomplishment of all program requirements including technical, schedule and cost objectives. He has direct access to the Divisional Vice President under whose cognizance the program is assigned.

The Program Manager is assisted by the Management Controls Manager whose responsibility it is to provide and maintain the program control and reporting documentation, the Subcontracts Manager under whose cognizance all subcontracts are placed, the Program Administrator whose responsibility is the reporting of all cost information and the Project Scientist whose concern is the maintenance of the scientific integrity of the instrumentation.

The Program Manager has reporting to him a number of project engineers from the various company departments whose skills are required in the accomplishment of the contractual objectives. Each of these project engineers are supported by a group of persons in the accomplishment of the detailed work.

### Management (1.1)

The Program Manager, supported by other members of the Program Office, will direct the activities and manage the resources at his disposal to meet the objectives of the contract. Specifically the following tasks will be performed:

Provide technical direction by means of meetings, directives and specifications.

Provide program management by means of the program and company organizations, the provisions in this management plan, and management directives.

Perform subcontract management using the resources of the subcontract group within the Program Office.

Conduct liaison with NASA/MSC for purposes of reporting and obtaining direction as required by the contract.

Provide handling and disposition of technical correspondence both incoming from and out-going to NASA/MSC, NAR and other agencies including subcontractors.

Provide authorizations as required for performance of work and placement of orders and subcontracts.

Perform reporting and submit documents as required by the contract.

Utilizing a Work Breakdown Structure, establish schedules and cost control reporting to enable the evaluation of progress made with resources spent.

Establish policies and procedures for the program as derived from the contract, company policy and NASA/MSC direction.

Disseminate information and data as required by the various program disciplines in the performance of their tasks.

Provide direction to production.

#### Schedule and Financial Reporting (1.2)

The Management Control Manager and the Program Administrator at the direction of the Program Manager will provide and maintain the means to evaluate progress and ascertain problems and to relate program achievements with resources expended through utili-

zation of the Work Breakdown Structure. Specifically the following tasks will be performed:

Establish budgets for all company disciplines required to meet the program objectives.

Establish and maintain master schedules defining extent and phasing of all required activities.

Establish and maintain milestone schedules for each work element to enable the measurement of performance.

Monitor expenditures and correlate with progress made.

Disseminate all necessary financial and schedule data required by contract and by the managers charged with task package responsibility.

Maintain all other program control correspondence.

Participate in the preparation of all NASA/MSC required reports.

Monitor all procurements.

Obtain necessary quotes and proposed information as a result of NASA/MSC direction or proposal requests.

Maintain cost records of purchased parts, materials and services.

#### X-ray Material (1.3)

All parts and materials required in conformance with the NASA/ MSC Contract NAS9-9983, X-ray Spectrometer, are procured under this package. Contract personnel are accounted for within the task packages assigned to the departments they work in.

#### Alpha Material (1.4)

All parts and materials required in conformance with the

NASA/ MSC Contract NAS9-9982, Alpha Spectrometer, are procured under this package. Contract personnel are accounted for within the Work Packages assigned to the departments they work in.

Documentation (1.5)

Documentation assistance will be provided in accordance with the requirements established by the contracts. Specifically the following support will be provided:

Technical writing and editing.

Preparation of forms, graphs, charts, tables, etc.

Photography, viewgraphs and slides.

Printing, reproduction, and typing.

This support will be used in the preparation of Monthly Progress Reports, proposals requested by NASA/ MSC and applicable plans and reports.

Travel (1.6)

All travel performed on NASA/ MSC Contracts NAS9-9982 and NAS9-9983 shall be charged to this task package.

Scientific Direction and Support (2.0)

The Apollo Lunar X-ray and Alpha Spectrometers Program, as an integral part of program organization, has a group of scientists, whose direction comes from the Project Scientist. This group continuously perform those tasks necessary to ensure no compromise in scientific performance. In general these tasks are related to the design, testing, prelaunch, launch, and post-launch phases of the program. In the case of the Alpha Spectrometer, the Principal Investigator at AS&E actively participates and monitors the scientific activity on the Program. For the X-ray Spectrometer, program scientific personnel maintain an active

Liaison with the Principal Investigator.

X-ray Scientific Support (2.1)

Provide continuous support in performance of the following tasks:

Define all critical parameters that have an effect on the performance of the instrument.

Evaluate breadboards of critical circuits to insure meeting the scientific requirements.

Maintain liaison with the Principal Investigator.

Evaluate the performance of the assembled instrument to ascertain that it meets all the scientific objectives.

Maintain cognizance of the engineering effort.

Periodically review the design details to whatever level necessary to ensure compliance of the instrument and GSE with the scientific objectives.

Participate to whatever degree necessary in the testing programs and review the test data.

Prepare data and calibration curves, that will be necessary in the preparation of the data programs and the interpretation of the scientific data.

Participate in all design reviews.

Participate in the definition of all interfaces with the spacecraft contractor to insure that the instrument operation will not be compromised in any respect.

Determine the requirements for the telemetry format and additional spacecraft related data necessary for the reduction of experimental data and analysis.

Alpha Scientific Support (2.2)

Provide continuous support in performance of the following tasks:

Define all critical parameters that have an effect on the performance of the instrument.

Evaluate breadboards of critical circuits to insure meeting the scientific requirements.

Maintain liaison with the Principal Investigator.

Evaluate the performance of the assembled instrument to ascertain that it meets all the scientific objectives.

Maintain cognizance of the engineering effort.

Periodically review the design details to whatever level necessary to ensure compliance of the instrument and GSE with the scientific objectives.

Participate to whatever degree necessary in the testing programs and review the test data.

Prepare data, calibration curves, etc., that will be necessary in the preparation of the data programs and the interpretation of the scientific data.

Participate in all design reviews.

Participate in the definition of all interfaces with the spacecraft contractor to insure that the instrument operation will not be compromised in any respect.

Determine the requirements for the telemetry format and additional spacecraft related data necessary for the reduction of experimental data and analysis.

### Alpha Data Reduction and Analysis (2.3)

Perform the following tasks associated with the handling of the Alpha data:

Prepare programs to handle the scientific data.

Establish methods for handling the scientific data.

Define operational parameters.

Using the programs above, perform post-flight data reduction and analysis.

Based on post-flight data reduction and analysis, interim reports containing the scientific results will be submitted after each flight. A final report containing the summation of all scientific results will be submitted.

### Design and Development (3.0)

The objective of this Work Package is to perform all those tasks required to provide design documentation for the Apollo Lunar X-ray and Alpha Spectrometers to the extent required to allow procurement, manufacture assembly, test and delivery of these end items with their ground support equipment. Included in this task is the reliability program, the direction of the safety program, configuration control, contract documentation preparation, support-to-production, drafting and production testing. These tasks are primarily performed within the Engineering Organization which is led by the Director of Engineering. Each Department within the Engineering Organization is directed by its Department Head who has assigned a Project Engineer to the Program and a group of engineers to support him. The Project Engineer reports to the Program Manager on all matters pertaining to the Program. This Work Package is composed of the following tasks.

### Electrical Engineering (3.1)

Design, develop, and test the electronics required to meet the experiment scientific objectives and the contract technical and environmental specifications and interface control documents.

This effort includes the following:

- Perform design and analysis of all electronic circuitry.

- Perform breadboard testing of all electronic circuitry to evaluate whether the technical, environmental and interface requirements have been met.

- Prepare drawings defining the electronic and packaging design.

- Prepare procurement specifications.

- Participate in meetings and presentations including interface meetings.

- Prepare data for inclusion into contract required documentation.

- Provide support to drafting in providing detailed designs.

- Provide manufacturing test procedures for all electronic modules, subassemblies, and assemblies.

### Mechanical Engineering (3.2)

Design and develop all mechanical elements including structures, frames, supports, brackets, and any mechanical hardware that are required to provide the mechanical and environmental properties to allow the instruments to meet the contract technical and environmental requirements and scientific objectives. Included in this effort are any electro-mechanical and thermal efforts.

This task includes the following:

- Perform design and layout effort to completely define the mechanical and thermal design of the instruments.

Perform environmental testing on critical components.

Establish and maintain up-to-date weight and center of gravity predictions.

Specify and design mockup, mass mockup, and hi-fidelity mockup.

Provide support to drafting in the preparation of the detailed drawings.

Participate in meetings and presentations including interface meetings.

Prepare a structural analysis.

Assist in the preparation of the electronic packaging concept and maintain cognizance of this effort.

Design handling fixtures and test fixtures.

Analyze in detail the thermal properties of the various mechanical elements and components to ensure proper environmental performance.

Construct a thermal flow diagram for use in the thermal analysis. Determine heat flows in the critical areas.

Conduct vibration testing of the mass mockup.

Prepare data for inclusion in contract required documentation.

### Systems Engineering (3.3)

Participate in the conceptual design effort to ensure that all reasonable design alternatives and tradeoffs have been evaluated. Evaluate ground support equipment concepts and ascertain the optimum concept together with the interface considerations. This task includes the following:

Evaluate conceptually the instrument design.

Perform spacecraft interface studies with particular emphasis on data transfer characteristics.

Evaluate ground support equipment concepts as they apply to the instrumentation design concept.

Establish instrument/ground support equipment interfaces.

Integrate and checkout the instrumentation interface with the ground support equipment.

Participate in meetings and presentations including interface meetings.

Study testing requirements and establish testing philosophy for all test operations on the program both in-house and in the field.

Prepare data for inclusion in contract required documentation.

Prepare documentation and specifications related to the ground support equipment.

#### Design Documentation (3.4)

Provide all drafting services and materials to completely detail the design for the Apollo Lunar X-ray and Alpha Spectrometers.

This task includes the following:

Provide drafting for electrical and mechanical drawings.

Participate in the engineering drawing release activity in accordance with established policy.

Incorporate all ECO's onto the required drawings.

Provide and maintain a current drawing tree.

Reliability and Safety (3.5)

Participate in the design of the instrumentation to ensure a maximum level of reliability, consistent with the reliability provisions in the contract, is incorporated into the Apollo Lunar X-ray and Alpha Spectrometers. Establish and enforce a safety program consistent with the contractual requirements. The following tasks will be performed:

Conduct a parts and materials program with the following elements of work:

Preparation and review of part reliability requirements.

Preparation of part screening specifications.

Liaison with part manufacturers.

Periodic preparation of parts and materials lists.

Liaison with NASA/MSC reliability personnel.

Evaluation of unknown materials to be considered for use on the program.

Review data as follows:

Procurement specifications

Drawings

Customer specifications

ECO's

Purchase Requisitions

Test specifications and plans

Test procedures.

Perform a Failure, Mode and Effects Analysis (FMEA).

Prepare a Single Failure Point Summary (SFPS).

Perform a Circuit Stress Analysis on the most commonly used circuits for conformance to applicable derating criteria.

Conduct a subcontractor/supplier control program.

Perform surveys as necessary to ascertain vendors capability to meet contract requirements.

Review vendor documentation.

Conduct design reviews.

Conduct liaison and provide reliability support to vendors.

Monitor vendors for performance in meeting reliability requirements.

#### Plans and Specifications (3.6)

Working in conjunction with other groups responsible for the preparation of contractual documents, prepare the documents listed below:

Instrument End Item Specification

Instrument Qualification Test Specification

Instrument Acceptance Test Specification

Instrument Pre-Installation Test Specification

Integrated System Test Specification

Instrument Qualification Test Procedure

Instrument Acceptance Test Procedure

Instrument Pre-Installation Test Procedure

Operation, Maintenance and Handling Procedures

Procurement Specifications

#### Electrical Engineering Support-to-Production (3.7)

Provide support to the Manufacturing Department to enable an efficient transition from the design phase of the program to the manufacturing phase. The following effort is included:

Design special tooling.

Design, assemble and test manufacturing test fixtures.  
Upon request, assist in any manufacturing problems related to the electrical design.  
Develop procedures and processes as required.  
Initiate ECO's as necessary resulting from manufacturing problems.  
Interpret manufacturing drawings.  
Participate on Material Review Board actions.  
Participate in evaluation of vendor performance.  
Assist as required in solving any vendor manufacturing problems.

Mechanical Engineering Support-to-Production (3.8)

Provide support to the Manufacturing Department to enable an efficient transition from the design phase of the program to the manufacturing phase. The following effort is included:

Design special tooling.  
Design, assemble and test manufacturing test fixtures.  
Upon request, assist in any manufacturing problems related to the mechanical design.  
Develop procedures and processes as required.  
Initiate ECO's resulting from manufacturing problems.  
Interpret manufacturing drawings.  
Participate on Material Review Board actions.  
Participate in evaluation of vendor performance.  
Assist as required in solving any vendor manufacturing problems.  
Supervise the assembly of any critical components.  
Design manufacturing fixtures.

### System Documentation (3.9)

Provide information and written material in the preparation of contractual documentation. Working with other groups, review the documentation for approach, correctness, etc. Working with the personnel assigned to Task 3.6, make the below documentation available for submission:

Instrument End Item Specification.

Instrument Qualification Test Specification.

Instrument Acceptance Test Specification.

Instrument Pre-Installation Test Specification.

Integrated System Test Specification

Instrument Qualification Test Procedure

Instrument Acceptance Test Procedure

Instrument Pre-Installation Test Procedure

Operation, Maintenance and Handling Procedures.

Procurement Specifications.

### Electrical Checkout (3.10)

Work with the Manufacturing and Quality Control Department, provide electrical checkout of all electronic hardware using test procedures. This task includes:

Checkout of all analog and digital modules.

Alignment of modules

Determination of any malfunction and initiation of any action necessary to dispose of, correct, and report malfunction.

Checkout and align all assemblies and instruments.

Design, fabricate and test any test fixtures, cables and test equipment necessary to support electrical checkout.

Participate as required in the acceptance and qualification test programs.

#### Ground Support Equipment (4.0)

Perform all required functions necessary to design, specify, manufacture, procure and checkout the required number of ground support equipments (GSE) that will enable checkout of the X-ray and Alpha Spectrometers. This work package is composed of the following tasks.

#### GSE Design (4.1)

Provide engineering to accomplish the design of the GSE. This task includes:

- Study concepts and configurations and evaluate various tradeoffs.

- Provide a specification to enable the procurement of those portions of the GSE to be subcontracted.

- Establish an instrument-GSE interface.

- Establish all interface parameters necessary to ensure that the GSE will perform as intended at the several test facilities both in-house and in the field.

- Test the GSE to ensure it meets all design and operational requirements.

- Provide all documentation that defines the GSE design.

#### GSE Fabrication and Assembly (4.2)

Provide the engineering, design and manufacturing support to enable the design, fabrication and assembly of four (4) GSE's. The following work will be accomplished:

- Provide detailed designs required to integrate all sub-contracted GSE elements into three fieldable GSE's and one laboratory GSE. This will include the design of an over-all structure, brackets, hardware and cabling.

- Perform the necessary manufacturing effort to provide the

required parts, pieces, cables for four (4) GSE's and perform the necessary assembly work for this number.

Programming (4.3)

Perform the required GSE computer programming to enable the operation and checkout of the X-ray and Alpha Spectrometers. These programs will enable the end-to-end checkout of both spectrometers and will constitute the test sequence to be used in acceptance and qualification testing.

Quality Control (5.0)

The Quality Control Department with a quality control engineer reporting to the Program Manager shall perform those duties associated with the quality procedures and requirements stated here.

Drawing and change control of procurement sources.

Identification, handling and storage of material.

Inspection and test

Process controls

Nonconforming article

Control of inspection, measuring and test equipment

Indication of inspection status

Preservation, packaging, packing and shipping

Sampling inspection

Records of inspections and tests

Corrective action

Cleanliness requirements

Government source inspection requirements.

Manufacturing (6.0)

The Manufacturing Department will provide all necessary skills services and materials necessary to fabricate and assemble four (4) X-ray and Alpha Spectrometers in accordance with the design

documentation including manufacturing drawings, parts lists, layouts, process specifications, and fixtures. The specific tasks within this work package are as follows.

#### Manufacturing Engineering (6.1)

Provide engineering to all phases of the manufacturing operation.

Provide tooling and fixture designs.

Ensure proper manufacturing processes and controls are available.

Provide aides-to-production.

Provide supervision of the manufacturing operation including manufacturing control.

#### Manufacturing Control (6.2)

Perform those tasks necessary to control the manufacture of prototype model, one qualification model and two flight models. Scheduling priorities shall be in accordance with the program milestones established for the programs. The following tasks will be performed:

Establish detailed schedules for the performance of all procurement, manufacturing, assembly, inspection and test.

Report manufacturing progress regularly.

Report areas of potential and actual impact and establish, if necessary, other methods for obtaining manufacturing goals.

Ensure availability of all necessary material, hardware, documentation, fixtures, etc. to perform each and every manufacturing effort on a timely basis to meet manufacturing goals.

Procure all necessary parts and materials.

Assemble module, subassembly, assembly etc. kits.

#### Electrical Fabrication (6.3)

Perform electrical fabrication and assembly for one prototype model, one qualification model and two flight models. Specific tasks to be accomplished are as follows:

Assemble components onto printed circuit boards in accordance with detailed manufacturing drawings.

Construct electronic cables and harnesses in accordance with detailed manufacturing drawings.

Assemble modules in accordance with detailed manufacturing drawings.

#### Mechanical Fabrication (6.4)

Perform mechanical fabrication and assembly for one prototype model, one qualification model and two flight models. Specific tasks to be accomplished are as follows:

Fabricate and assemble all necessary mechanical structures, enclosures, brackets, housings, etc. as defined by the detailed manufacturing drawings.

Provide all necessary processes as specified in the manufacturing documentation.

Fabricate and assemble all necessary manufacturing fixtures.

#### Material Fabrication (6.5)

Perform as specified in the manufacturing documentation material processing for one prototype model, one qualification model and two flight models. Specific tasks to be accomplished are as follows:

Provide potting and encapsulation.

Conformally coat all printed circuit boards.

Fabricate all printed circuit boards.

Incoming Inspection (6.6)

Electrically and/or mechanically in accordance with established criteria, all parts and materials obtained from outside sources to ensure full compliance with the requirements of the order. Ensure all necessary data required by the order is available. Maintain records as required to indicate actions taken.

In-Process Inspection and Test (6.7)

Perform in-process mechanical and/or electrical inspection and electrical testing in accordance with inspection criteria and documentation established for the program. Maintain records as required to indicate actions taken.

Instrument Testing (7.0)

This work package covers all testing activity associated with the conduct of instrument acceptance and qualification testing and environmental testing and evaluation of selected components. The following specific areas of testing have been established.

Systems Acceptance Testing (7.1)

Perform all necessary steps required to conduct acceptance tests on one prototype model, one qualification model, and two flight models. The procedure implemented will be the procedure established by the Acceptance Test Procedure approved by NASA/ MSC. This task will include that effort necessary to plan for the availability of all services, facilities, and personnel.

Reliability Acceptance Testing (7.2)

Perform all necessary steps required to assist in the performance of acceptance test on one prototype model, one qualification model, and two flight models. Specific tasks to be performed are the following:

Make certain that all required entries are made in the equipment log.

Review problems as they may effect reliability and safety.

If a failure occurs, participate in determining the cause of the failure.

Review all test results.

For any failures, initiate failure reporting, failure analysis and corrective action.

#### Quality Control Acceptance Testing (7.3)

Monitor the performance of the acceptance tests on one prototype model, one qualification model and two flight models. Ascertain that all tests required are performed in accordance with the procedure.

#### Systems Qualification Testing (7.4)

Perform all necessary steps required to conduct a qualification test on the qualification model. The procedure implemented will be the procedure established by the Qualification Test Procedure approved by NASA/MSC. This task will include that effort necessary to plan for the availability of all services, facilities and personnel.

#### Reliability Qualification Testing (7.5)

Perform all necessary steps required to assist in the performance of the qualification test on the qualification mode. Specific tasks to be performed are the following.

Make certain that all required entries are made in the equipment log.

Review problems as they may effect reliability and safety.

If a failure occurs, participate in determining the cause of the failure.

Review all test results.

For any failures, initiate failure reporting, failure analysis and corrective action.

Quality Control Qualification Testing (7.6)

Perform all necessary steps required to monitor the performance of the qualification tests on the qualification model.

Mechanical Component Testing (7.7)

Perform mechanical and thermal tests of selected components to determine if they meet the environmental requirements. Publish technical reports and memoranda reporting results of testing and possible redesigns if required. If required, reduce and analyze the data.

Reliability Component Testing (7.8)

Assist in the conduct of component testing to the extent of helping prepare the component test procedures and providing technical support.

Integration and Field Support (8.0)

In order to assure the most expeditious handling of field requirements and problems, a group will be established both at the contractor's and at the various field facilities to support the various instruments and GSE's. This group will work with and support the spacecraft contractor in readying the instrument for flight.

X-ray Field Support (8.1)

All X-ray field support is included in this task package.

Alpha Field Support (8.2)

All Alpha field support is included in this task package.

### 2.3 Management Controls

As described in Section 2.2, Organization, the total work to be accomplished on the X-ray and Alpha Spectrometers Program has been divided into a number of functional elements called tasks which have been assigned to the various skill centers within AS&E. Each task is assigned to a work package manager within the skill center and he is the person responsible to the Program Manager for accomplishing that task within the constraints imposed by his task package which is the basic management control tool on the program. Each task package is reviewed by the Program Office and the responsible individual weekly. Each task package is composed of a number of documents which are:

Task Description - A description of all work to be done. These descriptions are in Section 2.2.3.

Milestone Chart - A schedule for accomplishment of work within the task.

Manpower Loading Chart - A schedule by labor category of all personnel to be used in the accomplishment of the work within the task.

Manpower Performance Chart - A chart defining the projected average cumulative manpower and weekly manpower required to achieve the defined milestones within a task package. This chart is updated weekly and given to the Program Manager and work package manager to compare labor expended versus milestones achieved.

Other documents utilized in the control of the program but at the work package level are:

Budget Authorization - A tabulation of all cost dollar budgets by month and work package. The total dollar budget for a work package is the sum of the dollar budgets for each task within the work package.

Work Package Summary- A chart which reports progress made and resources expended by work package.

The following sections discuss each of the above documents and shows examples:

#### 2.3.1 Work Package Summary

The Work Package Summary Chart shown in Figure 2-3 presents in summary form the major work package milestones and compares with these the resource expenditure actuals with those budgeted. Specifically, the following information is presented:

Statement of Work - A brief statement of the work to be performed in the work package.

Milestones - Major milestones within the work package with an indication of progress against these milestones.

Milestone Performance - The number of scheduled milestones that are completed during the reporting period. The number of scheduled milestones is the sum of all milestones in the task packages for the same period.

Monthly Expenditure - The actual cost dollars expended in the work package for the reporting period compared to cost dollars budgeted.



Manpower Expenditure - A comparison of budgeted and actual manpower, in man-weeks, for the reporting period.

Cumulative % Completion (\$)- A comparison against budget of the cumulative percentage completion in terms of cost dollars through the reporting period.

### 2.3.2 Budget Authorizations

The budget authorizations in matrix form are shown in Figures 2-4a and 2-4b. The dollars shown are cost dollars and are listed by month and work package. The dollars for each work package are the sum of all dollars in the individual task packages within the work package.

### 2.3.3 Manpower Performance Chart

The manpower performance chart shown in Figure 2-5 defines the projected cumulative average manpower in man-weeks and weekly manpower in man-weeks for a task package. These projections are based on the work defined in the applicable task description and the events in the milestone chart. By tracking weekly on the performance chart the cumulative manpower actuals to date and progress against the task milestones on the milestone chart, an indication of performance is obtained. Indications of schedule and/or cumulative manpower variance can be readily detected by comparing manpower performance and milestone performance.

Other information on this chart is the task package title, the ADN's (Account Distribution Number), the responsible person, the date of issue and the period of performance. In some cases, there will be two ADN's (one X-ray number and one Alpha number) per task package reflecting the fact that the task is common to both spectrometer contracts. The projected cumulative manpower

APOLLO LUNAR  
BUDGET AUTHORIZATION

	Jan 1970	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
<b>1.0 Program Management</b>	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.5	3.5	3.5
	8910--	8910--	8910--	8910--	8910--	8910--	8910--	8910--	8910--	5878--	5878--	5878--
<b>2.0 Scientific</b>	3.4	3.4	4.0	4.0	4.0	4.4	4.7	4.7	4.7	3.7	3.7	3.6
	4744--	4744--	5717--	5717--	5717--	6027--	6270--	6270--	6270--	4752--	4752--	4601--
<b>3.0 Design and Development</b>	59.2	48.0	46.4	33.7	30.4	24.4	22.3	21.3	12.6	6.3	3.7	3.5
	63743--	55075--	50422--	37162--	33641--	27910--	25977--	24584--	14857--	7595--	4997--	4997--
<b>4.0 GSE</b>	4.6	5.4	3.5	3.3	2.7	0.1						
	5238--	5870--	3692--	3469--	2802--	151--						
<b>5.0 Quality Control</b>	3.1	3.3	3.3	3.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	3765--	3987--	3987--	3987--	2874--	2874--	2874--	2874--	2874--	2874--	2874--	2874--
<b>6.0 Manufacturing</b>	16.0	29.8	46.5	34.3	32.3	20.7	11.0	9.3	8.3	3.3	1.1	0.5
	13484--	23752--	35455--	26164--	24759--	15195--	8234--	7109--	6477--	2184--	728--	331--
<b>7.0 Instrument Testing</b>	2.6	3.9	5.9	8.1	7.8	8.6	8.6	7.4	7.8	5.9	5.1	3.7
	3479--	4690--	6560--	9008--	8554--	9645--	9645--	8149--	8311--	6295--	5444--	4420--
<b>8.0 Integration and Field Support</b>												
Monthly M/P Total	93.9	98.8	114.6	93.0	85.4	66.5	54.8	50.9	41.6	26.0	20.3	18.0
Monthly D/L \$ Total	103363--	107028--	114743--	96064--	88379--	71985--	63032--	59018--	48815--	30851--	25795--	24223--

"This Summary Represents Budgets Authorized for Four Systems."

Figure 2-4a. Budget Authorization

APOLLO LUNAR  
BUDGET AUTHORIZATION (Continued)

	Jan 1971	Feb	Mar	Apr	May	Post Flight	Mgmt Res	Sub Total M/M	Total M/M	C-T-C	Total \$
1.0 Program Management	3.5 5878--	3.5 5878--	3.5 5878--				32.5 32403--		98.5	147861--	173706--
2.0 Scientific	3.6 4601--	3.6 4601--	2.3 3160--			13.0 15827--			70.8	93770--	113427--
3.0 Design & Development	4.0 5424--	2.9 3630--	0.9 859--				35.0 28315--		354.6	389102--	575444--
4.0 GSE									19.6	21221--	26753--
5.0 Quality Control	1.3 1761--								32.7	40479--	48068--
6.0 Manufacturing									223.1	171842--	188305--
7.0 Instrument Testing	0.1 216--	0.1 216--							75.6	84632--	84632--
8.0 Field Support	0.9 1122--	1.3 1607--	1.1 1304--	1.0 1113--					13.0	16071--	16071--
	13.4 19002--	11.4 15932--	7.8 11201--	1.0 1113--		13.0 15827--	77.5 68680--		887.9	965059--	1226406--

"This Summary Represents Budgets Authorized for Four Systems."

Figure 2-4b. Budget Authorization

**MANPOWER PERFORMANCE CHART**

Rev. #3

PROGRAM: Apollo Lunar  
 TASK: 3.3 System Design  
 ADN: 646-410, 645-410  
 RESPONSIBILITY: R. Gaul  
 DATE OF ISSUE: 25MAR70  
 PERIOD OF PERFORMANCE: Thru 1 July 1970

04-2

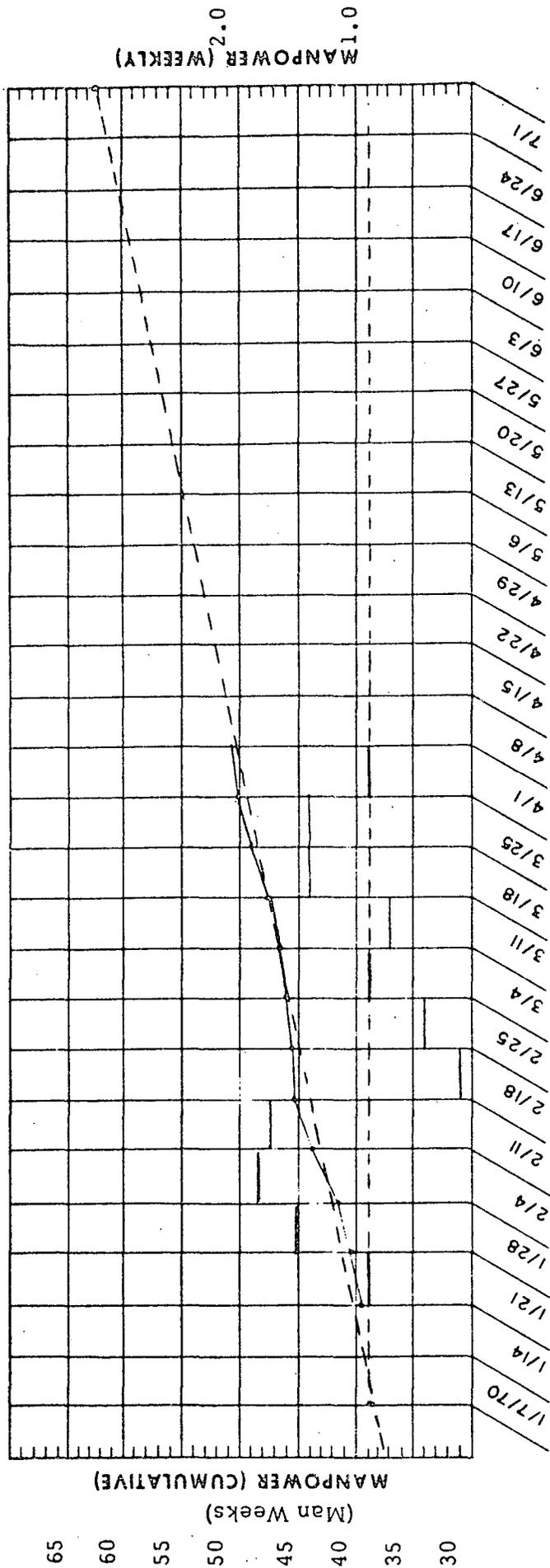


Figure 2-5. Manpower Performance Chart

line and the reported cumulative actuals to date is the effort (projected and cumulative) required to accomplish the common task of both contracts.

#### 2.3.4 Manpower Loading Charts

The manpower loading chart shown in Figure 2-6 is a listing by labor category and task package of all labor in man-months per month projected to be spent in the accomplishment of the task. This listing tabulates all labor through the end of the program. Again, this chart contains the task package title, originator (work package manager), the date of issue, and the applicable ADN's.

#### 2.3.5 Milestone Chart

The milestone chart shown in Figures 2-7a and 2-7b contains all milestones established for the task package. On the average, for each task package, milestones have been set at two-week intervals.

AS  
AE

**MANPOWER LOADING CHART**

**ORIGINATOR** J. Stein

**DATE** 3-16-70 **Rev. #1**

2.1 X-Ray Scientific Support  
2.2 Alpha Scientific Support  
2.3 Alpha Data Reduction & Analysis

**PROGRAM** APOLLO LUNAR

**ADN NO.** 645/646 - 910/920/930

**TASK**

	1970												1971				
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	P.F.
2.1 X-Ray Scientific Support (2) 646-910	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.8	0.8	0.8	0.8	0.8	0.8	0.8	
(3)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
2.2 Alpha Scientific Support (2) 645-910	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
(3)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
2.3 Alpha Data Reduction & Analysis (1) 645-920				0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.1
(2)				0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	5.7
(3)						0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.6
(4)						0.3	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	4.6

F-703A

Figure 2-6. Manpower Loading Chart

**AS4E** MILESTONE CHART

1 of 2

DATE 25 March 1970

PROGRAM APOLLO LUNAR

WORK PACKAGE

1.1 MANAGEMENT

1970

Task	Task Description	JAN			FEB			MAR			APR			MAY			JUN			JUL			AUG		
		4	11	18	1	8	15	1	8	15	5	12	19	3	10	17	7	14	21	5	12	19	2	9	16
1.1	S Program Management	✓																							
1.1.1	C Critical Design Review																								
1.1.2.1	S Subsystem Checkout-Proto																								
	C Subsystem Checkout-Proto																								
.2	S Combined System c/o - Proto																								
	C Combined System c/o - Proto																								
.3	S Acceptance Test - Proto																								
	C Acceptance Test - Proto																								
.4	C Sell-Off Proto																								
1.1.3.1	S Subsystem Checkout-Flt.#1																								
	C Subsystem Checkout-Flt.#1																								
.2	S Combined System c/o - Flt.#1																								
	C Combined System c/o - Flt.#1																								
.3	S Acceptance Test - Flt.#1																								
	C Acceptance Test - Flt.#1																								
.4	C Sell-Off Flt.#1																								
1.1.4.1	S Subsystem Checkout-Qual Unit																								
	C Subsystem Checkout-Qual Unit																								
.2	S Combined System c/o-Qual Unit																								
	C Combined System c/o-Qual Unit																								
.3	S Acceptance Test - Qual Unit																								
	C Acceptance Test - Qual Unit																								
.4	C Sell-Off Qual Unit																								
1.1.5.1	S Subsystem Checkout - Flt.#2																								
	C Subsystem Checkout - Flt.#2																								
.2	S Combined System c/o - Flt.#2																								
	C Combined System c/o - Flt.#2																								
.3	S Acceptance Test - Flt.#2																								
	C Acceptance Test - Flt.#2																								
.4	C Sell-Off Flt.#2																								
1.1.6	S Qualification Test																								

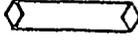
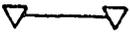
Apollo Lunar  
F-288 A

Figure 2-7a. Milestone Chart



APOLLO LUNAR  
Management Plan Legend

A. Work Package Summary

1.  Continuous activity. First diamond indicates start date, last diamond indicates stop date. Progress indicated by shaded portion.
2.  Milestone. Completion indicated by shading.
3.  Milestone slipped. First triangle indicates original schedule date. Last triangle indicates re-scheduled completion date. Completion indicated by shading last triangle.

B. Manpower Performance Chart

1. Horizontal dashed lines indicate weekly manpower budgets and are read off right hand column (Manpower weekly).
2. Ascending dashed line indicates budgeted cumulative manpower and is read off left hand column (Manpower cumulative).
3. Horizontal solid lines indicate weekly manpower actuals and are read off right hand column (Manpower weekly).
4. Ascending solid line indicates actual cumulative manpower and is read off left hand column (Manpower cumulative).
5. Vertical solid line (with enclosed number beside it) indicates manpower re-allocation. Enclosed number refers to note at bottom of chart. Note refers to re-allocation number.

C. Manpower Loading Chart

1. Number in parentheses after task title refer to labor category.

Labor categories are as follows:

- (1) Project Scientist and/or Engineer
- (2) Senior Scientist and/or Engineer
- (3) Scientist and/or Engineer
- (4) Engineering Aide
- (5) Technician
- (6) Machinist
- (7/8) Designer/Draftsman
- (9) Technical Illustrations

D. Milestone Chart

1.  Milestone. Start or stop date. Completion indicated by shading.
2.  $\overset{n}{\nabla}$  Material milestone delivery schedule where  $n$  equals the number of units to be delivered. Where there is no number then it is assumed to be one (1) unit.
3.  Milestone slipped. First triangle indicates original schedule date. Last triangle indicates re-scheduled completion date. Com- indicated by shading last triangle.

## 2.4 ENGINEERING REPORT ON THE PERFORMANCE OF THE ALPHA/X-RAY SPECTROMETERS FOR APOLLO 15 and 16 MISSIONS

### 2.4.1 Alpha Particle Spectrometers

The overall performance of the Apollo 15 and 16 instruments was nominal. All housekeeping voltage monitors were nominal and remained stable throughout the missions and temperature excursions. The performance of all ten (10) Alpha detectors was nominal as evidenced by the data from the on-board calibration sources. The source count distributions were similar to that observed during preflight testing. Detector 6 of the Apollo 15 instrument was sporadically noisy, which was sufficient to make the Detector 6 data unusable during those periods; however, it did not affect the data from the other nine detectors.

### 2.4.2 X-Ray Spectrometers

The overall performance of the Apollo 15 and 16 instruments was nominal. All housekeeping voltage monitors were nominal and remained stable throughout the missions and temperature excursions. From all indications the cycling of the attenuation mode and source calibration rods was proper. Nominal operation of the four (4) detectors was evidenced by data resulting from the on-board sources. There was, however, a high count rate observed in Channel 1 of Detector 1 of both flight instruments, but this fact did not appear to have a significant effect on the instruments' performance.

## 2.5 ACCOMPLISHMENTS

Several significant accomplishments resulted from the two NASA/ MSC contracts. Two areas, that of Alpha data reduction and analysis and analysis of galactic X-ray sources are still active and are expected to provide a significant contribution to the scientific community.

The specific areas of accomplishment, outlined in detail, are:

- 2.5.1 Alpha Particle Spectrometer for Apollo 15 and 16
- 2.5.2 Screening and Testing of Surface Barrier Detectors.
- 2.5.3 System for non-dispersive Analysis of Lunar X-rays from Apollo.
- 2.5.4 Method of Application and Testing of Sodium based thermal control paint (Z-93)

### 2.5.1 Alpha Particle Spectrometer for Apollo

#### 2.5.1.1 Brief (Abstract) Description.

The Apollo Alpha Particle Spectrometer was developed for the specific purpose of detecting and mapping the alpha particle emission of the Moon from the scientific instrument module (SIM) of the Apollo spacecraft. The spectrometer consists of an array of 10 silicon surface barrier charged particle detectors, each with an active area of  $3 \text{ cm}^2$  and a dedicated low noise-preamplifier and a data handling system that analyzes and sorts the pulse amplitude of each detected particle into 256 channels covering the interval between 4.5 and 9 MeV of energy. Each event is analyzed in energy and passed on to the telemetry system. Accumulation of the events in time intervals of arbitrary size is performed on the ground during the data analysis process. There are several subsidiary components in the system such as

a collimator that limits the field of view of the detector array to a  $\pm 45^\circ$  cone about the detector normal and built-in radioactive sources for calibration.

2.5.1.2 Description (In detail) as follows

a. General Purpose of the Item

The Alpha Particle Spectrometer was designed for the specific purpose of detecting and mapping from lunar orbit the alpha particle emission from the Moon. It was also required to meet the interface and manned spacecraft requirements for operating in the Scientific Instrumentation Module of the Apollo spacecraft.

Natural concentrations of uranium and thorium in lunar material will produce radon gas which will diffuse to the surface of the Moon. The radon atoms will remain trapped in the Moon's gravitational field until they undergo alpha particle decay. As a result of the decay process, monoenergetic alpha particles will be emitted into free space and radioactive daughter products of radon which are also emitters of monoenergetic alpha particles will be deposited on the surface. From lunar orbit the alpha spectrometer will detect the alpha particles due to the natural decay processes by observing several line components in an energy spectrum. Regions of enhanced alpha particle activity denote either high concentrations of uranium and thorium or high porosity for the diffusion of gas.

b. Improvement and/or Advantages Over Prior Methods, Materials, or Devices

The Apollo Alpha Particle Spectrometer is the largest area array of silicon surface barrier detectors that has been con-

structed for use in space for any known program. Also the energy resolution of the entire array is about equal in quality to that of individual detectors. The improvement over prior devices is its sensitivity for detecting alpha particles, particularly monoenergetic alphas. The large sensitivity is a direct result of its large area. The Apollo Alpha Particle Spectrometer has about a factor of a thousand larger area than an instrument used on the lunar lander of Surveyor V, VI, and VII and its energy resolution is at least as good.

c. Detailed Description Including as Applicable the Explanation of the Principle of Operation.

The Alpha Particle Spectrometer measuring equipment is contained in three assemblies; the Alpha Detector Assembly, the Alpha Processor Assembly; and the Low Voltage Power Supply. These assemblies are housed in an enclosure which also contains an X-ray Spectrometer (see Figure 2-8). The enclosure is designed to fit into the Apollo Scientific Instrument Module. The Alpha Particle Spectrometer operates off the spacecraft 28 volt buss, controlled by a switch in the Apollo Command Module, and consumes 13 Watts of power.

Alpha Detector Assembly

The Alpha Detector Assembly consists of ten silicon barrier detectors, dedicated charge sensitive pre-amplifiers, bias control circuitry and temperature monitors.

The silicon surface barrier detectors function in the usual manner for these devices. A charged particle impinging upon a detector loses energy in it by ioni-

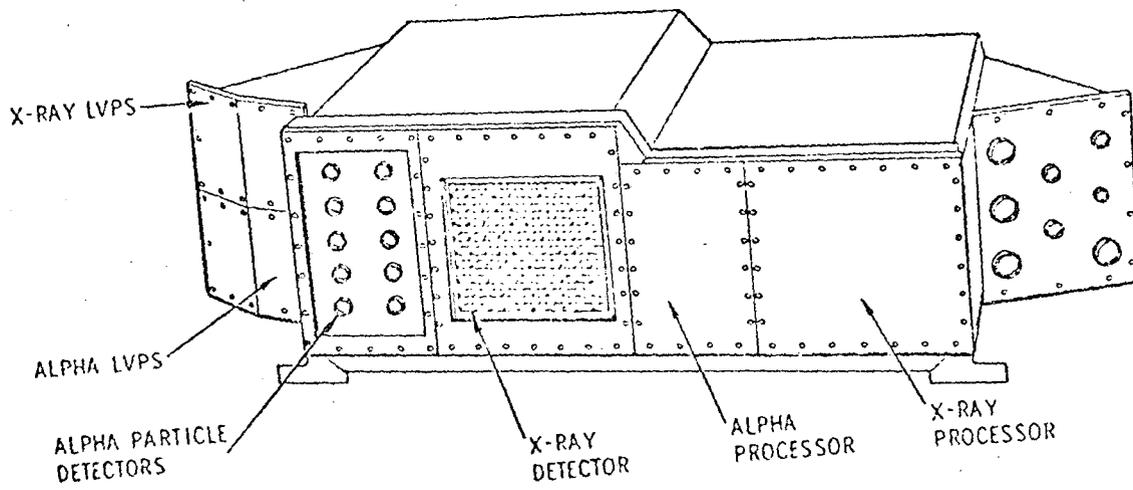


Figure 2-8. Alpha/X-Ray Particle Experiment Enclosure

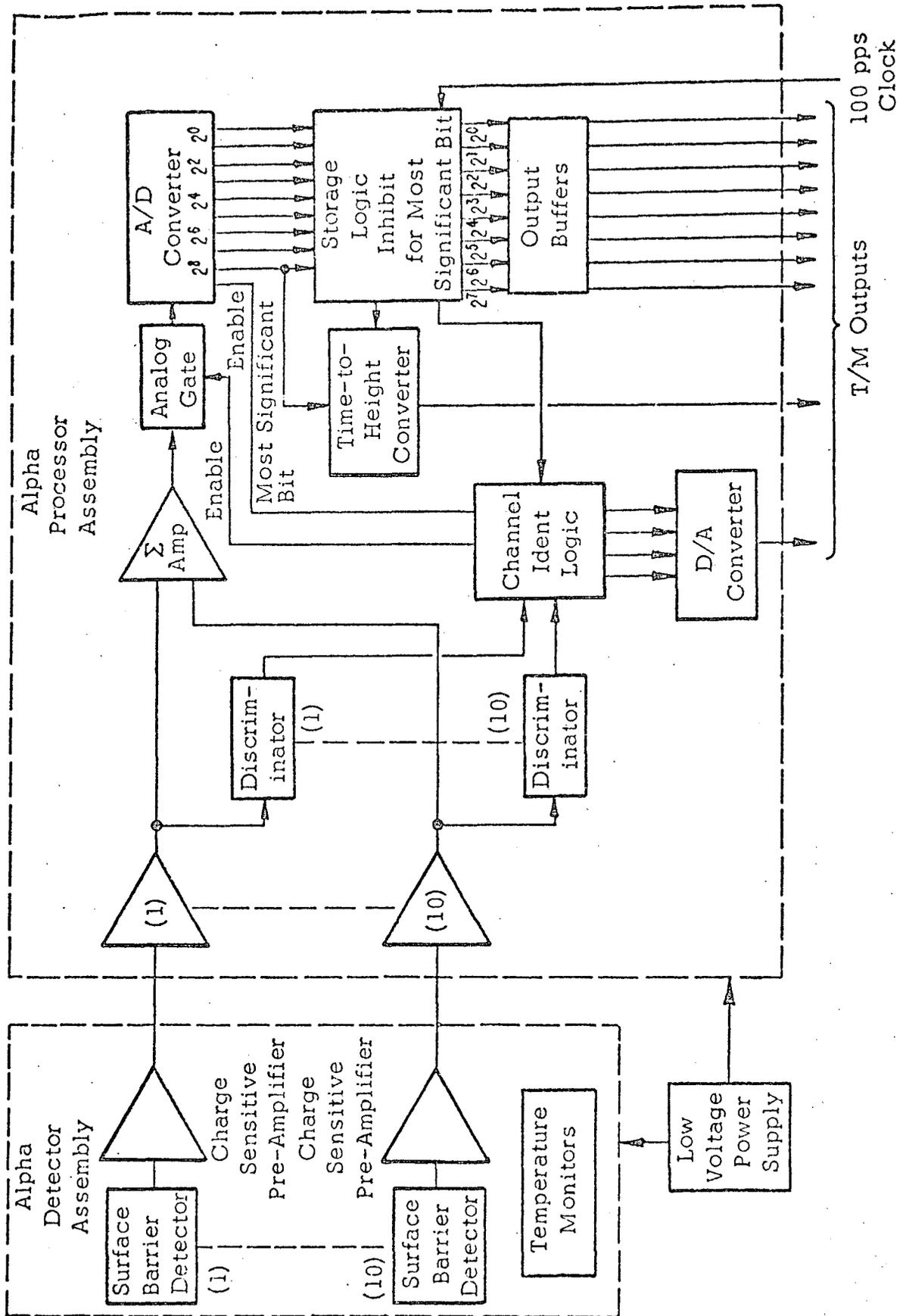


Figure 2-9. Alpha Particle Spectrometer Block Diagram

zation and excitation. In response to this effect the detector delivers a pulsed quantity of charge into a low noise preamplifier that is proportional to the energy loss of the particle in the active volume of the detector. The depth of the active volume was specifically selected to be 120 microns. Hence, by range energy considerations, a distinction between a proton and an alpha particle and a determination of its energy on the basis of the quantity of charge in the pulse is almost unambiguous. Protons are the largest source of background; however, no proton is capable of depositing more than 4 MeV of energy in the detectors except through rarely occurring nuclear interactions.

A small collimator is mounted in front of each detector which limits the field of view to a  $\pm 45^\circ$  cone about the detector normal. Consequently, extraneous effects from the spacecraft are minimized and the instrument field of view is restricted to a well-defined region of the moon. Each collimator contains a low-level fixed radioactive source which serves to calibrate the energy response of the system. Since detector channel identification is retained in the telemetry data compensation for gain drift is possible.

The gain and rise time of each detector/preamplifier combination is adjusted such that an alpha particle of a given energy produces an identical output.

Detector temperature is monitored via telemetry by means of thermistors mounted on two detectors. The temperature monitor also serves as the control for a

protection circuit which interrupts the -40 volt detector bias supply when the detector temperature exceeds +42°C.

#### Alpha Processor Assembly (Figure 2-9)

The output of each preamplifier is fed to a biased amplifier which passes only those signals which exceed a precisely set threshold voltage. In this way, background events resulting from cosmic ray interactions which leave only a small energy deposit are eliminated, as well as any noise contribution from inactive detector channels. The outputs of the ten biased amplifiers are summed to produce a single signal channel which is then integrated in a pulse shaper. The shaped signal passes through an analog gate (if it is enabled by the analog gate control) to another shaper which eliminates the analog gate switching transients. The signal then passes to a 512 channel analog to digital converter (pulse height analyzer) whose output is a digital representation of the input signal pulse height. The energy region of interest (4.5 to 9 MeV) lies in ADC channels 256 through 512. This information is used in the processing logic to inhibit events not in the region of interest.

The output of each biased amplifier is also fed to a discriminator which triggers each time a pulse is passed to the summing amplifier. The discriminator outputs are fed into the channel identification logic and then to a digital-to-analog converter which provides an analog voltage to telemetry. This voltage level, when time correlated on the ground with the

pulse height analyzer data, provides detector channel identification

When a discriminator signal is detected by the channel identification logic, all its inputs are inhibited and the flip-flop which controls the analog gate sets to the enable state. The analog gate remains enabled until the ADC measures the signal peak (Ready Signal goes low) at which time the analog gate control flip-flop is reset, inhibiting the analog signal.

As previously indicated, the region of interest lies between ADC channels 256 and 512, thus the most significant bit ( $2^8$  bit) will be at logic 1. At the completion of the ADC conversion period, the ADC Ready signal goes high and interrogates the MSB output. If it is not a logic 1, both the ADC and D/A outputs are reset to zero (no signal condition). If the MSB is a logic 1 the ADC outputs and D/A level are held in their respective output buffers for the duration of the current telemetry readout cycle. At the start of the next telemetry readout cycle, the ADC output is transferred to the storage logic and the ADC and the channel identification logic are reset, thus ready to analyze the next detector signal. During this readout cycle, the telemetry system interrogates the instrument outputs after which the storage logic and the D/A converter are reset.

The telemetry readout signal (10 pps) is derived in the storage logic from the SIM 100 pps clock which runs in synchronism with the telemetry system.

A time to height converter provides an estimate of the pulse count in situations where the number of input pulses exceed the number that can be processed by the system. The circuit is reset to zero at the start of each telemetry period. An RC network is then allowed to charge. At the time the ADC most significant bit registers a logic 1 the RC voltage level is sampled and held until interrogated by the telemetry readout signal.

d. Features of the Item Believed to be New

The new features of the Apollo Alpha Particle Spectrometer is its large overall area. To our knowledge, the ten units constitute by far the largest array of silicon surface barrier detectors or solid state detectors in general that has been assembled for use in space. Thus, it is by far the most sensitive alpha particle detector that has been made. This has been accomplished without loss of energy resolution compared to what could be expected from a single detector. The data handling system of the Apollo instrument is also designed to provide the most critical alpha particle energy analysis yet attempted in space.

e. Applications

At this point we do not see any applications for this instrument outside of related lunar-planet̄ary orbital or surface experiments. Non-space applications do not usually require as large an area or sensitivity as the Apollo device.

f. What are Possible Extensions of this Item?

Possible extensions are: (1) larger versions that will

map the radon evolution of the Moon in more detail,  
(2) extension to satellite of other planets.

## 2.5.2 Screening and Testing of Surface Barrier Detectors.

### 2.5.2.1 Brief (Abstract) Description

An Alpha Particle Spectrometer was developed for the specific purpose of detecting and mapping the alpha particle emission of the Moon from the scientific instrument module (SIM) of the Apollo spacecraft. A disclosure of new technology describing this Spectrometer has been submitted via American Science and Engineering Document ASE-2700.

The Spectrometer utilized an array of 10 silicon barrier detectors, each with an active area of  $3 \text{ cm}^2$ . The detectors available for use on this program were manufactured to "good commercial practice" and since a high level of reliability assurance was needed a comprehensive detector test program was established which included 100 per cent screening and testing of the detector at two stages of the spectrometer manufacturing process.

As a result of a detailed failure reporting and analysis program, additional test requirements and criteria were implemented into the test program as it progressed to detect inherent failure modes of detectors and screen out incipient failures. The major detector parameters used as accept/reject criteria were leakage current, noise, and resolution. The various combinations of environmental tests, to which the detectors were exposed were: hard vacuum, temperature cycling, and

photosensitivity. The result of this program was a significant improvement in the reliability of the surface barrier detectors in their system application.

2.5.2.2 Description (In Detail) as Follows

a. General Purpose of the Test

The Screening and test program was designed around the critical performance parameters of the surface barrier detector to cull out those detectors containing inherent failure modes that were time dependent, environmentally sensitive, or incurred mishandling during fabrication.

b. Improvement and/or Advantages Over Prior Methods, Materials, or Devices

Based on the large quantity of detectors required and an unexpectedly high initial screening failure rate, a comprehensive test program was established to determine the boundaries of the infant mortality rate and isolate it to the lowest device test level. There is no known standard screening and test procedure in existence which is considered adequate for screening large surface area silicon surface barrier detectors. This screening method developed at AS&E addressed itself to obtaining silicon barrier detectors suitable for use in a deep space application.

c. Detailed Description Including, As Applicable, the Explanation of the Principle of Operation

To aid in understanding the screening and test program, brief descriptions of the detector, test configurations for resolution, leakage current, noise, and photosensitivity are provided herein. Key parameters for determining the acceptability of the detector to meet system performance requirements are included.

1. Detector Description

(a) Detector Configuration (Mechanical)

Figure 2-10 is a diagram of a typical silicon surface-barrier detector. In this illustration, D is the effective diameter corresponding to the active area of the device;

$W$  is the depth of the sensitive (depletion) region;  $L$  is the total thickness of the Si wafer; and  $L-W$  is the thickness of the undepleted region.

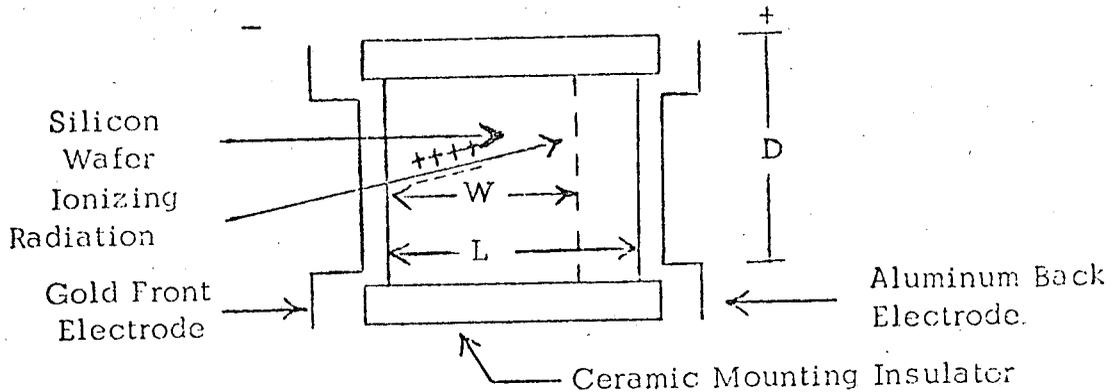


Figure 2-10 Typical Surface Barrier Detector

The region  $W$  corresponds to the portion of the silicon that contains an electric field resulting from an externally applied reverse bias ( $V_b$ ) on the diode. Free charge carriers created in this region by the ionizing radiation are separated under the influence of the electric field. In response to this effect the detector delivers a pulsed quantity of charge into a low noise preamplifier that is proportional to the energy loss of the particle in the active area of the detector.

(b) Detector Configuration (Equivalent Electrical Circuit with Preamp)

Figure 2-11 is an equivalent circuit for a surface barrier detector and its first preamplifier stage. In this figure,  $C_d$  is the detector capacitance,  $R_L$  corresponds to reverse leakage in the diode, and  $R_s$  is the total diode series resistance.  $R_b^s$  is the load resistor through which bias is applied.  $C$  provides DC decoupling,  $C_s$  represents all stray capacitance between detector and preamplifier, and  $C_A$  is the effective input capacitance of the preamplifier.

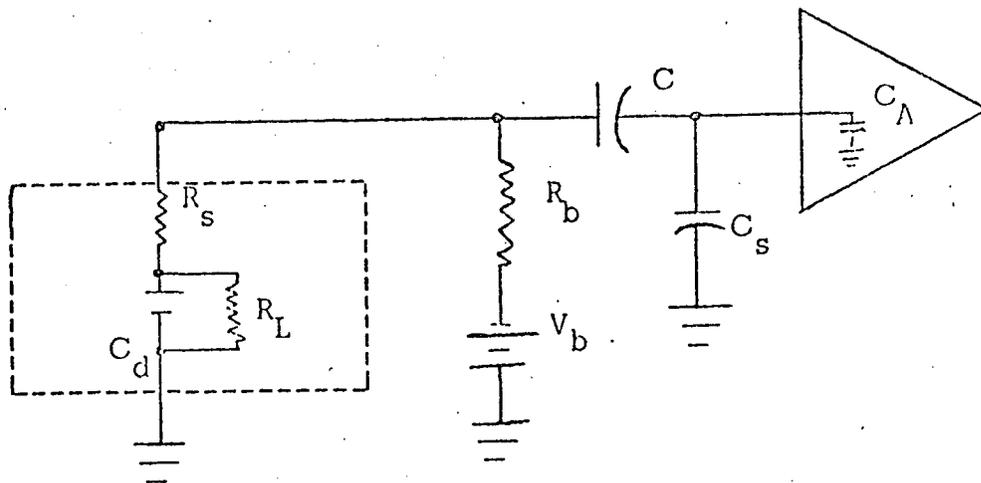


Figure 2-11 Equivalent Circuit for Surface-Barrier Detector and First Preamplifier Stage

$C_d$  and  $C_s$ , in conjunction with  $R_s$  have a large effect on risetime and resolution characteristics of the detector system and, in fact, dictate the characteristics of the preamplifier design. In addition, these components affect the noise characteristics of the system.  $R_L$  is also an important factor in detector design since the leakage current through  $R_L$  is a prime source of noise in the detector system and, therefore, must be minimized.

## 2. Test Configurations

### (a) Resolution Measurements

Resolution as related to nuclear particle detection systems is a "figure of merit" which measures the ability of a system to distinguish adjacent energy levels from one another, thereby identifying different particle energy levels,  $e_1, e_2, \dots, e_n$ . In performing resolution measurements in a vacuum, both an energy source or pulse generator may be used. Be-

cause of room atmosphere resistivity to alpha particles, only a pulse generator was used for non-vacuum conditions of test. In the case where a source of alpha particles with a fixed energy is used, resolution was determined by irradiating the surface of the detector and observing the resulting distribution of energy levels. The dispersion around the peak channel in a properly designed system is due principally to the noise of the detector and the associated electronic circuits and to small random variations in the particle energy of the radioactive material provided as a source.

In the second case, a pulse generator was used to inject a pulse of known height directly into the junction between the detector and preamplifier, thus simulating a particle of known energy. When done with a precision pulse generator, the dispersion in measured pulse height was reduced to that caused by the amplifier noise and the electrical properties of the detector. Figure 2-12 is the block diagram of the resolution test set-up.

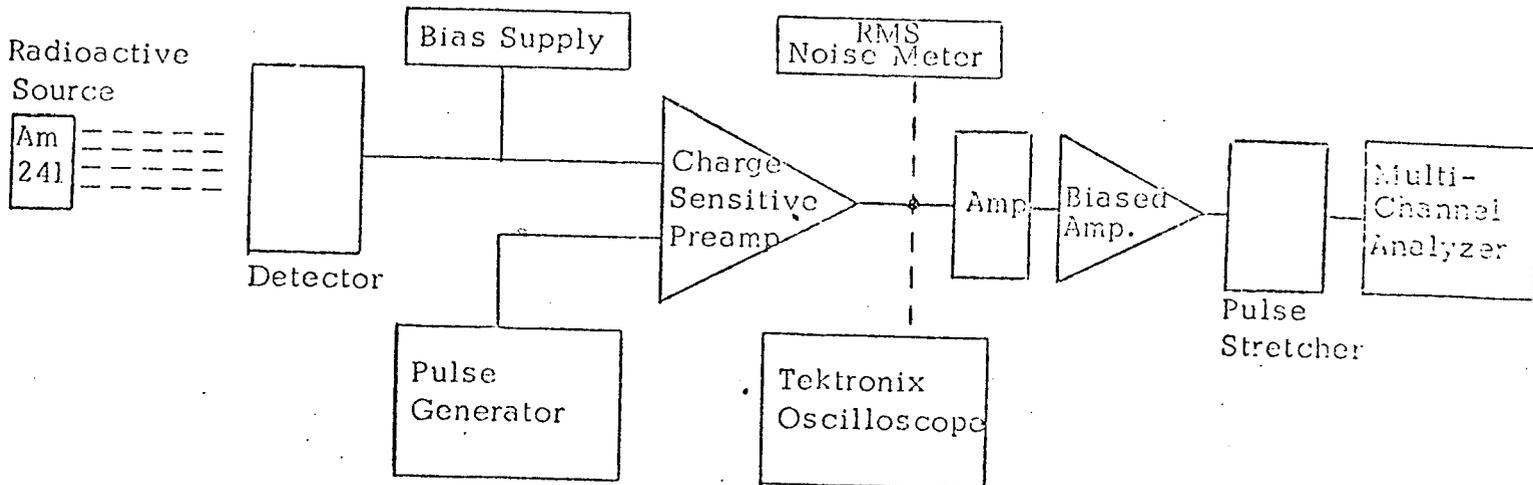


Figure 2-12 Test Set-up for Resolution and Noise

(b) Noise Measurements

The surface barrier detector is electrically characterized by its relatively high capacitance (300 pf) and leakage current ( $1 \mu a$  max) as used on the AS&E Alpha Spectrometer. In this system it is the noise in the detector and amplifier/processor chain that limits resolution below the value established by the analyzer. Noise riding on the signal presents a time-varying height to the analyzer which sorts the various pulse heights into corresponding energy channels. This results in spreading of the distribution and degrading of the resolution.

Noise generated at the detector stage of the system has a considerable effect on the resolution of the system. In properly manufactured solid-state detectors, leakage current is normally the major contributor to detector noise. However, if a detector displays photosensitivity, the exposure to light will have a contributory effect on detector noise. Figure 2-12 shows the test set-up for measuring noise at the detector test level. The amplifier, biased amplifier, pulse stretcher, and multi-channel analyzer are not required in the test set-up. Leakage current is measured by inserting a microammeter in series with the detector signal output. Noise measurements may be taken at the output of the preamplifier, amplifier, or biased amplifier. However, consideration should be made for the bandwidths of each unit in the signal processing chain.

(c) Photosensitivity

Solid-state detectors are inherently photosensitive and must be made relatively insensitive to light. Photons entering the detector create free charge-carriers which contribute to the leakage current of the device and, subsequently, contribute to the noise of the detectors. In detector

charge-sensitive systems where the detector and preamplifier are capacitively coupled, the steady state (DC) leakage of photocurrent is blocked while the AC component is passed as noise. Typical of this is a modulated light source such as a 60-Hz fluorescent lamp.

Electrodes are normally "evaporated" onto the silicon in a vacuum-deposition process to make the detector light-tight and provide a uniform distribution of the electrical field across the P-N junction of the silicon wafer. Therefore, photosensitivity tests provide a measure of the electrode density and an indication of significant surface imperfections or anomalies.

The basic test set-up of Figure 2-12 can be utilized for measuring detector photosensitivity. In this case, a circular fluorescent light source is set-up in place of the radioactive source approximately 6 inches from the front electrode of the detector and measurements of noise are taken, as previously described.

### 3. Detector Test Program

Detector testing may be classified into three major categories:

1. Final tests by the manufacturer
2. Screening tests at AS&E
3. Operational tests

The significant portion of the screening and test program was concerned with categories 2 and 3. Final tests were conducted by the manufacturer prior to identification of the device, and were designed to validate the detector electrical characteristics. The first test conducted by the manufacturer consisted of measurements

of noise, resolution, and leakage current at room temperature in a vacuum followed by 16 hours of operation in a vacuum. Following the 16-hour operating period, the measurements were repeated. Subsequently, this test was modified to include temperature cycling in a vacuum, and the total operating test period was increased to a minimum of 36 hours.

The screening tests conducted at AS&E were focused on the detector and were designed to reveal weaknesses which could lead to eventual failure during operation of the device. These tests are defined in AS&E document TP132-136 and include temperature cycling between  $-30^{\circ}\text{C}$  and  $+40^{\circ}\text{C}$  in a vacuum of  $10^{-3}$  Torr and 168 hours of room ambient burn-in. During the temperature-vacuum portion of this test, noise, resolution, and leakage current were measured. During burn-in, noise (at room ambient) was measured both with illumination and no illumination, for photosensitivity determination of the detector. Following the burn-in test, leakage current and resolution were remeasured.

During the temperature-vacuum test the detector was mounted alone in a metal bell-jar. The environment is light-tight and virtually impervious to electrically radiated interference. During the burn-in operation, the detector was mounted, with nine other, in a fixture located on a bench in the test area and operated at room ambient conditions.

Operational testing was the next level occurring after the screening test. These are the detector assembly tests of

TP132-520, consisting of the detector fabricated into an assembly with the preamplifier and post amplifier. During all of these tests the detector remained installed in its subassembly, module 132-520. Initial test was conducted with the assembly in a vacuum (20 microns) at room temperature. Both illuminated and non-illuminated noise measurements were made as well as resolution measurements.

A 48-hour burn-in test (in accordance with TP132-176) was performed next at room ambient temperature and  $10^{-5}$  Torr vacuum, with continuous measurement and monitoring of wideband noise.

d. Features of the Item Believed to be New

Photosensitivity testing was accomplished by measuring noise output in wideband and narrowband VRMS as a method of detecting surface imperfections and anomalies. In addition, application of burn-in principles were applied to this type silicon surface barrier detector to eliminate infant mortality from the device life cycle and achieve a zero hazard rate, based on failure rate data compiled.

e. Applications

Other instrumentation having long term life/high reliability requirements and using silicon surface barrier detectors.

f. What Are Possible Extensions of This Item

Similar screening and testing procedures could possibly be applied to other semiconductor types of detectors.

### 2.5.3 System for non-Dispersive Analysis of Lunar X-rays from Apollo

#### 2.5.3.1 Brief (Abstract) Description

The X-ray Spectrometer developed for Apollo is an instrument built to the rigid specifications of the manned space program designed to measure the abundance of several elements by detecting characteristic fluorescent X-rays. The new features of the instrument compared to previous systems are its documented reliability for spaceflight and its much improved sensitivity by virtue of a very large detector area. The instrument is intended to be used to measure the chemical composition of the Moon on Apollo Missions 15 and 16 by remote sensing from lunar orbit.

#### 2.5.3.2 Description (In Detail) as Follows:

##### a. General Purpose of the Item

Contract NAS9-9983 required that AS&E design, fabricate test and integrate an X-ray spectrometer, meeting the reliability standards of the manned spacecraft program, into the scientific instrument module (SIM) of the Apollo spacecraft. It consists of three main subsystems: (a) three large-area proportional counters having "state-of-the art" energy resolution and 0.001-in. thick beryllium windows; (b) a set of large area filters that will discriminate principally between the characteristic X-ray radiation of aluminum, silicon and magnesium; and (c) a data handling system for accumulating counts, sorting them into 8 channels of pulse height analysis, and relaying the data to the spacecraft telemetry.

Under normal solar conditions the instrument is designed to detect the percentage abundance of at least aluminum,

silicon, and magnesium. Under more active solar conditions, heavier elements can also be detected.

b. Improvement and/or Advantages over Prior Methods, Materials or Devices.

This is the first X-ray analysis instrument designed to function in lunar orbit and the first time in the United States space program that chemical composition studies based on X-ray fluorescent methods will be accomplished in space, or for that matter, chemical composition measurements by remote sensing techniques. A laboratory technique has been extended and scaled up in size to work with very low intensities and in difficult environments.

c. Detailed Description Including as Applicable the Explanation of the Principle of Operation

1. Principle of Operation

The principle of operation is as follows: X-rays from the lunar surface are produced by the interaction of the Sun's X-rays. The lunar X-rays contain characteristic lines representing elements found on the surface. From differences in counting rates of the three counters, one containing an aluminum filter, the second a magnesium filter, and the third, no filter and applying pulse height analysis to the counter signals, characteristic X-ray lines of various elements can be resolved from each other and the background. A fourth counter monitors the solar X-ray spectrum and determines the effective X-ray temperature of the Sun. With information from all four counters we can determine the absolute abundances of several elements.

## 2. Equipment Description

### (a) X-ray Detector Assembly

The X-ray Detector Assembly consists of three proportional counter detectors, two X-ray fixed filters, mechanical collimators, an in-flight calibration device, temperature monitors, and associated electronics. The detector assembly senses X-ray emitted from the moon's surface and converts them to voltage pulses which are processed in the X-ray processor assembly. Provisions for in-flight calibration are made through programmed calibration sources which, upon command, assume a position in front of the three detectors for calibration of gain, resolution, and efficiency. Thermistors located at strategic points sense the temperature of the detector assembly for telemetry monitoring and temperature control of the detectors through heaters located near the proportional counter windows.

### (b) Proportional Counters (Figure 2-13)

The three proportional counters are identical, each having an effective window area of approximately  $25 \text{ cm}^2$  which consists of 0.001-inch-thick beryllium. The proportional counters are filled to a pressure of one atmosphere with the standard P-10 mixture of 90 percent argon, 9.5 percent carbon dioxide, and 0.5 percent helium. Filters are mounted across the beryllium window aperture of two of the proportional counters to change the wavelength sensitivity. The filters consist of foil in the range of 0.2 to 0.5 mils thick; one being magnesium and the other aluminum. The third counter does not contain a filter.

# X-RAY SPECTROMETER FUNCTIONAL CONFIGURATION

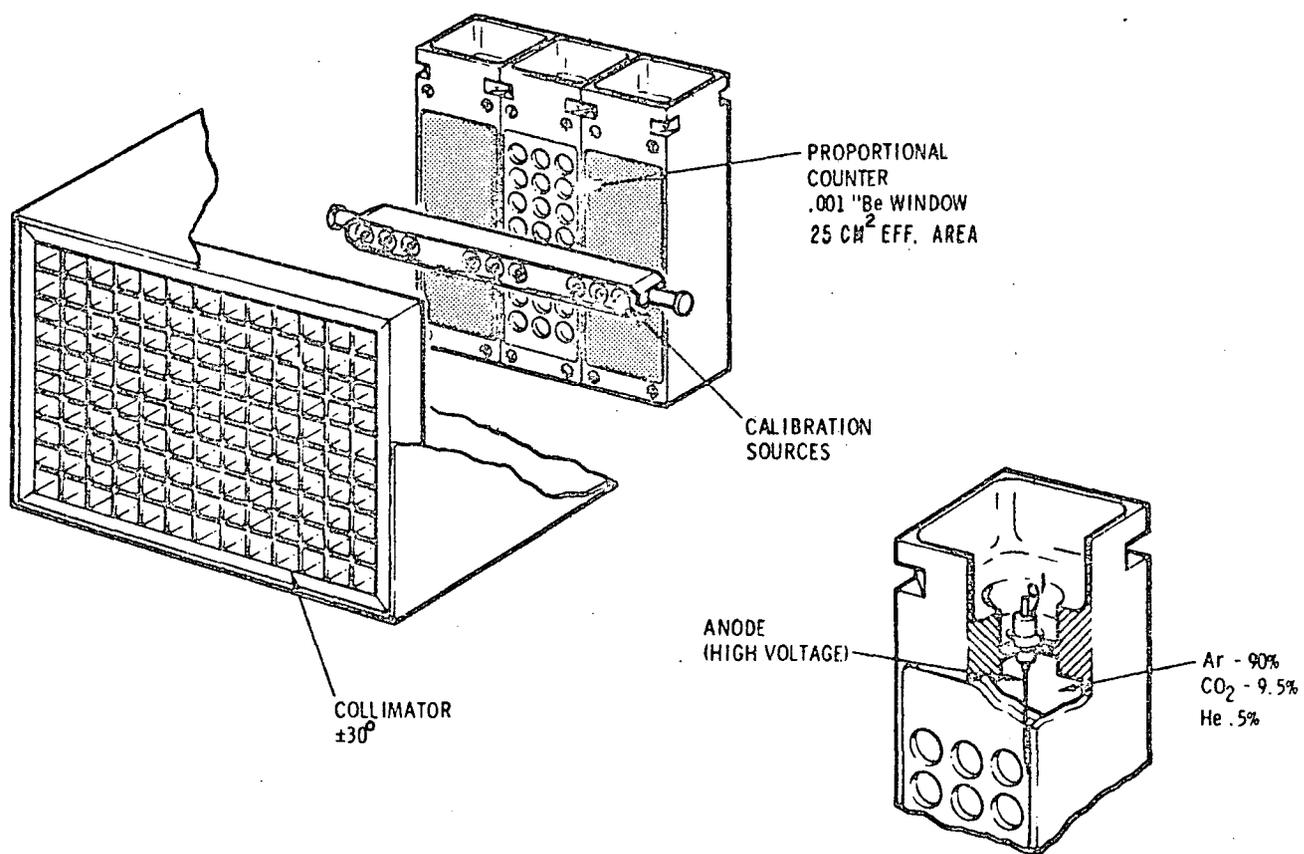


Figure 2-13

A single collimator assembly is used to define the FOV of the three proportional counters as a single unit. The collimator consists of multi-cellular baffles, which cover a large sensitive area and high resolution but are restricted in the FOV. The FOV determines the total flux recorded from the lunar surface and the spatial resolution of the moon. The FOV is specified as  $\pm 30^\circ$  full width half max (FWHM) in two perpendicular directions. The FWHM is the total angular width at which the collimator falls to half of its peak response.

X-ray photons passing through a proportional counter beryllium window ionize the gas inside by an amount proportional to their energy. A very stable high-voltage power supply provides a bias voltage of 2250 volts for operation of the proportional counters. This high voltage across the counter produces an electrical field gradient and hence a multiplication effect which results in a output that is proportional to the X-ray energy. Mounted on each proportional counter is a charge-sensitive pre-amplifier which converts the input charge to an output pulse by storing it on an integrating capacitor. This has a fast rise time, determined primarily by the response of the preamplifier, a slow decay, determined by the integrator decay time, and an amplitude proportional to the X-ray energy. The preamplifier gain is set for an output scale factor of about 0.2v/KeV. Each of the three preamplifier outputs are applied to the X-ray processor assembly which sorts the outputs according to the peak amplitude level.

(c) In-Flight Calibration

The in-flight calibration device consists of a calibration

rod with radioactive sources that normally face away from the proportional counters. Upon command from the X-ray processor assembly, the rod is rotated  $180^{\circ}$  by a solenoid driver, thereby positioning the sources facing the proportional counters. Magnetically sensitive reed relays provide feedback signals indicating when the rod is fully in a calibrate mode or fully in a non-calibrate mode. These feedback signals are flag bits in the data telemetry output. The calibrate command signal is generated in the X-ray processor assembly. The calibration cycle repeats every 16 minutes and lasts for 64 seconds.

(d) Detector Temperature Control and Monitor

A thermistor mounted near the proportional counter windows senses the detector temperature and generates the signal that is used to control the detector heaters. Heater control consists of on-off switching with the switching temperature being about  $-20^{\circ}\text{C}$ . A second thermistor mounted on the proportional counter senses proportional counter temperature which is converted to an analog voltage and sent to telemetry. A thermistor located on the X-ray detector assembly frame senses its temperature which is also converted to an analog voltage and sent to telemetry.

(e) X-Ray Processor Assembly

The X-ray processor assembly processes X-ray data received from the X-ray detector assembly and the solar monitor. The lunar X-ray data is sorted, counted, stored, and sent to telemetry. The solar X-ray data is counted, stored, and sent to telemetry; the data having been already sorted in the solar monitor. Processing of the data from one detector is shown in a functional block

diagram in Figure 2-14. The pulse received from the charge-sensitive preamplifier is amplified and operates up to eight voltage discriminators, depending on its voltage level. The discriminator outputs are processed logically in the pulse routing logic to obtain an output pulse in one of eight data channels, depending on the highest level discriminator operated. The pulses from each data channel are counted by the counters in the counter-shift register logic. Every 8 seconds the contents of the counters are transferred to the shift registers, and the counters are reset. The data is then sequentially shifted out of the shift registers to telemetry at a 10-word-per-second rate. Each TM word consists of 8 bits. Each counter is 16 bits long thereby supplying two TM words. The TM word output sequence is divided into four groups of 20 words each. They are obtained from the 20-word-long shift registers which are sequentially gated through the output multiplexer by the main timing. The multiplexer gate duration for each shift register output is 2 seconds (0.1 second-per-word) thereby obtaining an X-ray PHA data cycle period of 8 seconds from the four shift registers. Each pulse from the charge-sensitive preamplifier is also processed by a pulse shape discriminator (PSD) which distinguishes X-ray events from background. The PSD gates off the pulse routing logic thus preventing non-X-ray events from being counted.

At the start of the TM data sequence are four sync words consisting of fixed bit patterns which provide a unique identification of the start of a data cycle. Included in the data output are 16 words from the eight counters for each

# X-RAY SPECTROMETER BLOCK DIAGRAM

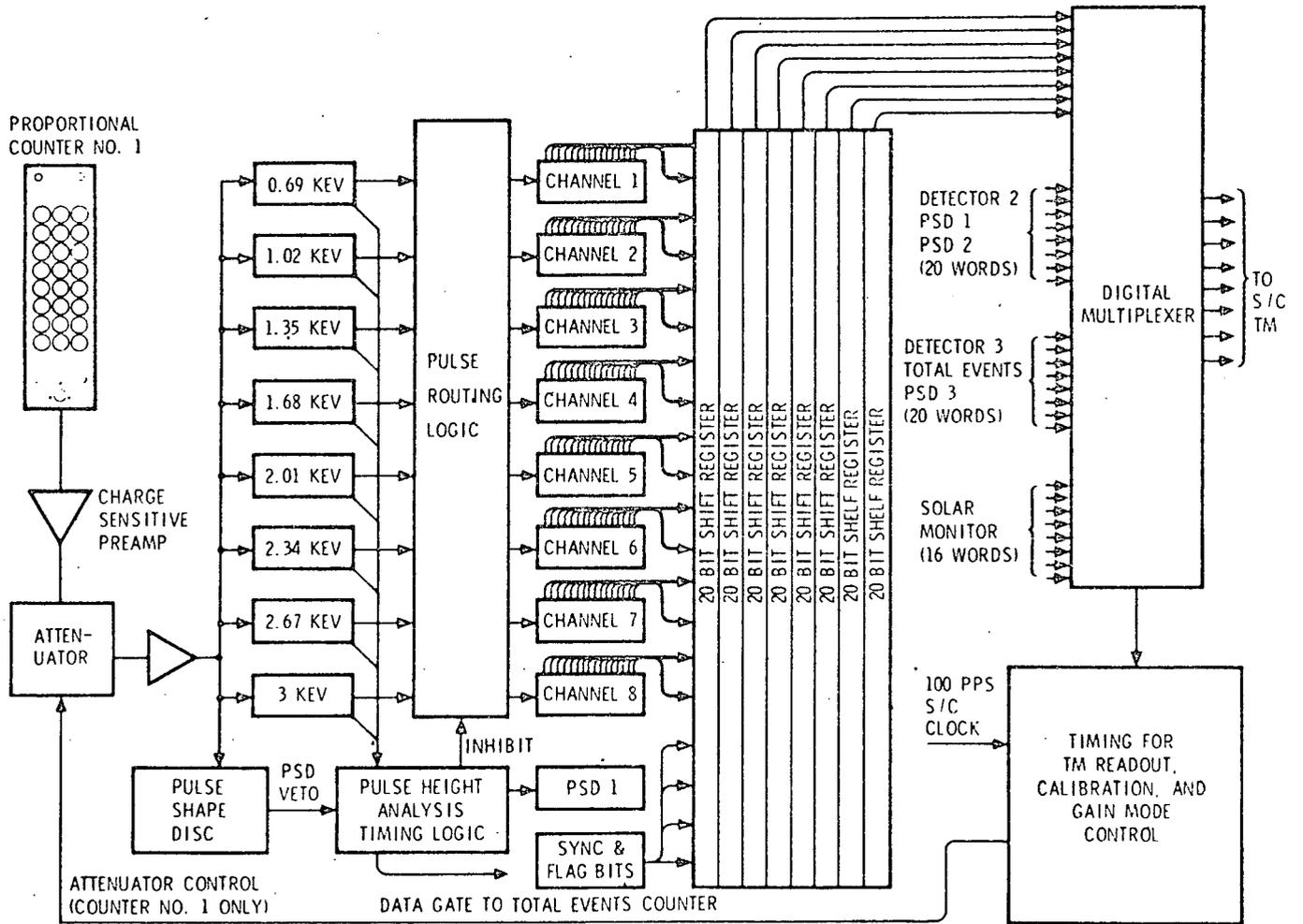


Figure 2-14

of the detector sets; PSD events for detectors 1, 2, and 3; a total events count, and four flag bits. The total events count is equal to sum of the counts in each of the eight data counters for all four detectors divided by 16. This provides redundancy for verification of data counts.

(f) Solar Monitor Assembly (SMA)

The SMA consists of a solar X-ray detector (proportional counter) and a solar X-ray pulse analyzer. The high-voltage power supply for the proportional counter is contained within the assembly. The solar X-ray detector is an unfiltered proportional counter (Figure 2-15) which converts incident X-rays into electrical pulses suitable for further processing by the solar X-ray pulse analyzer. The solar X-ray pulse analyzer functions and operates in the same manner as the first stages of the X-ray processor assembly providing a digital signal on one of eight possible output lines. The eight output lines are connected to the digital multiplexer of the X-ray spectrometer for further processing.

3. Duty Cycle Requirements in Lunar Orbit

(a) Lunar Orbit

Minimum of 10 continuous hours of operation is required.

Full sunlit lunar surface coverage is required. Full dark side coverage is desired consistent with gamma-ray spectrometer coverage.

(b) Features of the Item Believed to be New

1. The instrument represents a unique approach to the problem of determining chemical composition by remote sensing. It utilizes the flux of X-rays from the Sun as the excitation source for analyzing lunar chemical composition.

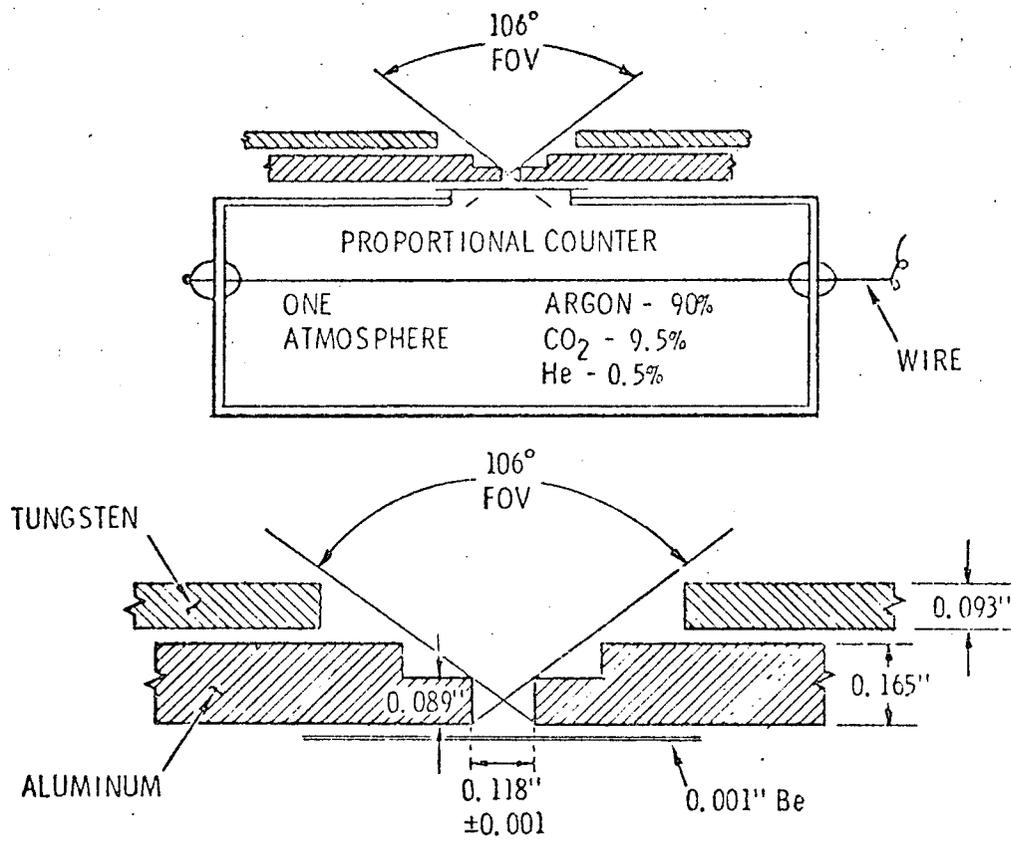


Figure 2-15. X-Ray Solar Monitor Counter

2. Large sensitivity of the instrument. Because of its large area, the instrument has about two orders of magnitude sensitivity greater than laboratory devices.

3. This is the largest set of proportional counters containing thin windows, i. e., 0.001-inch beryllium that has been designed to operate in earth orbit and beyond.

4. Ability to function in space.

(c) Applications

This technique could be applied to on-line chemical composition determinations in industry. For example, an instrument similar to the Apollo instrument could be used to determine the composition of certain alloys if a suitable excitation source were included. A field instrument for chemical composition analysis based on these principles could be used for determining composition of rock.

(d) What are Possible Extensions of the Item?

Possible extensions of this item are: (1) larger versions that will map the chemical composition of the lunar surface in more detail; (2) measurement of chemical composition of satellite of other planets and asteroids; (3) observation of galactic X-ray sources during TLC (Trans-Lunar Coast) and TEC (Trans-Earth Coast). This application has been utilized on Apollo XV and is expected to be utilized on Apollo XVI.

2.5.4 Application and Testing of Sodium-Based Thermal Control Paint (Z-93)

Z-93 was considered as the most likely thermal control coating for the front surfaces of the Lunar instrument in September of 1969.

However, in the late fall of 1969 it was discovered that the natural radioactivity of the potassium in the potassium-silicate binder formulation of Z-93 might interfere with the operation of the experiment. This information initiated studies of the availability of a sodium-silicate binder formulation of Z-93. This latter compound was also checked for the possible effects on the experiment. The sodium silicate formulation was given a clean bill of health scientifically and thermally.

At the Lunar Program Review held at AS&E on 5 March 1970, the concern over the use of the potassium-silicate binder Z-93 led to the formal use of the sodium silicate formulation. The review Minutes state, "Clearance has been given for Z-93 coating use. The sodium silicate formulation of the coating will be used to avoid possible problems associated with trace radioactivity of potassium . ( $K_{40}$ ). "

A degradation in the adhesive qualities of the modified Z-93 occurred at the conclusion of Lunar Qualification Acceptance testing. After consultation with various experts in the Thermal Coating field, with special emphasis on Z-93 (including IITRI MSFC, GSFC, MSC, AEC and others) it was clear that the difference in variables recommended by all concerned was extreme; that is, everyone knew the proper application technique, albeit none of the coatings seemed to meet all the requirements in total. Therefore, a scheme was devised, whereby one could utilize best engineering judgement and choose what appeared to be the most critical variables and thus perform meaningful tests. It was the intent of this study to investigate the effects of critical parameter variation associated with the Lunar Thermal Coating. Considerations were with respect to paint application and the compliance with environmental constraints. The major mechanism used in the evaluation was the designed experiment.

Preliminary testing showed that high temperature curing tended to degrade coatings, priming did not seem necessary and substrate thickness was independent of adhesion. These variables were therefore not included in the more comprehensive tests that followed. Engineering group discussions to determine the most critical parameters reduced the variables to the following:

A. Curing Cycles

- 1) Room temperature -  $75 \pm 15F^{\circ}$  for 10 days.
- 2) Vacuum Bake -  $75 \pm 15F^{\circ}$  for 5 hours followed by vacuum bake at  $10^{-3}$  Torr,  $115 \pm 5F^{\circ}$  for 10 hours

B. Surface Finish

- 1) Alconox
- 2) Sand Blast plus Alconox
- 3) Oakite
- 4) GSFC

C. Thickness of Coating

- 1) 0.003 inch (1-2 passes)
- 2) 0.004 inch (2-3 passes)
- 3) 0.005 inch (3-4 passes)
- 4) GSFC (2 passes)

D. Intermediate Coatings

Fog (Water Mist)  
No intermediate coating

E. Binder Ratio

Percent by weight

	Binder ( $NaSiO_2$ or $KSiO_2$ )	Pigment (ZnO)	Reducer ( $H_2O$ )
I. GSFC +25% $H_2O$	17	51	32
II. 30 cc	22	52	26
III. 40 cc	27	49	24
IV. 50 cc	32	45	23
V. 40 cc + 20% $H_2O$	26	46	28
VI. "0" $H_2O$	41	59	

Samples were prepared using these variables. Visual inspection of these samples lead to these initial conclusions. First, some ratio of each component of the formulation is necessary because a balance of application and adherence is required. For example, with every little reducer, a paste-like quality, leads to difficult application. Also as thicker coatings are applied, cracking, crazing and checking is enhanced.

Two hundred eighty samples were coated. Half of these were cured in the vacuum bake cycle and half at room temperature. The room temperature cure gives satisfactory results but those which are vacuum baked are also satisfactory. Since the vacuum bake was a shorter cure cycle and time was of the essence, it was the chosen technique. Exhibit A shows the results of samples tested for adhesion after thermal vacuum cycling. The conclusion that either sodium silicate binder can be used effectively is in conflict with opinions of the other experimentors but has none-the-less been shown by this investigation. Substrate finish was deemed extremely important. Results of this investigation show that the substrate must be clean and free from any impurities, but it does not substantiate achieving these characteristics in a specific fashion.

The formulation found to exhibit the greatest adherence was that of formulation IV or 50 cc of binder. Clearly the addition of water (formulation VI) had extremely poor adhesive qualities. Fog (a water mist between coats) was found to hinder adhesion. Minimum thickness of coating was found to give optimum results.

EXHIBIT A

Summary of Results of Z-93 Adhesion Test

Vacuum Bake Cure  
After Thermal Vacuum

CYCLING PER LUNAR QUALIFICATION PROCEDURE

	<u>Variable</u>	<u>%Passed</u>	<u>#Passed</u>	<u>#Tested</u>
BINDER RATIO	30 cc	80 %	27	34
	40 cc	86	31	36
	50 cc	100	36	36
INTERMEDIATE COATING	Mist Coat	85 %	45	53
	*No Mist Coat	92	49	53
BINDER TYPE	K	89 %	48	54
	*Na	89	46	52
SURFACE FINISH	Sand Blast	89 %	31	35
	*Alconox	86	30	35
	Oakite	91	33	36
COATING	*.003 inch	97 %	34	35
	.004	91	32	35
	.005	78	28	38

\*Present Parameters being used in Application of Z-93

### 3.0 SCIENTIFIC AND TECHNICAL APPROACH

#### 3.1 Alpha and X-Ray Spectrometer and GSE

##### 3.1.1 Introduction

The Alpha/X-ray Spectrometer is functionally two instruments. The two Spectrometers are independent but have been combined for convenience of packaging and to secure space and weight savings by means of a common integrating structure and thermal shield.

##### 3.1.2 Alpha Spectrometer

The function of the Alpha Spectrometer is to detect and measure the energy of the alpha particles emitted by the radon isotopes and their daughter products. The sensing elements are ten totally depleted silicon surface barrier detectors. They are each approximately 100 microns thick, 3 cm<sup>2</sup> active area, have a 90° field of view, and operate at -50 volts bias. Additional gold, aluminum and nickel layers were used at the contacts to assure light tight performance. The thickness of the detectors was chosen so that any background protons (deuterons or tritons) would give an output pulse of less than that for a 5 MeV alpha particle while the output for alpha particles up to 12 MeV would be linearly proportional to energy. This precludes the necessity for discriminating against other particles in any other way.

The ten detector preamplifier outputs are merged in a single summing amplifier and processed by a single analog-to-digital converter (ADC). While the use of one ADC minimizes the complexity of the hardware, it also means that the noise from all ten preamps is summed, resulting in a resolution degradation of about a factor of three. To circumvent this, each preamplifier has a bias offset

of approximately 350 keV. This effectively removes the noise and allows the use of a single ADC without resolution degradation. The ADC converts the energy pulse into a 9-bit digital signal. If the most significant bit is a 1, the ADC is disabled and the digital signal held until the next telemetry readout (every 100 milliseconds). If the most significant bit is zero, the ADC is reset and the next pulse is processed. This allows the instrument to digitize to a 9-bit accuracy and only transmit 8 bits. This means that only the upper half of the digitized energy range is telemetered. Physically this is reasonable since the alpha energies of interest range from 5.3 to 8.8 MeV and it also prevents the usage of telemetry time by any low energy background. The actual telemetered energy range of the instrument was from 4.7 to 9.1 MeV. Parallel circuitry generates an analog signal from 0.25 to 4.75 volts, in steps of 0.5 volts, which identifies the detector which originated any given pulse.

Since the digital telemetry is limited to 80 bits/second (10 counts/second), an additional circuit is used which generates an analog signal proportional to the time from the end of one telemetry read cycle to the sensing of the first pulse with energy greater than 4.7 MeV. This allows the dead time correction of the data should the count rate exceed about 20 counts/second. Exclusive of housekeeping, the output consists of an 8-bit energy word, an analog voltage identifying the detector, and an analog voltage exponentially proportional to the count rate.

Five of the detectors had energy calibration sources in their field of view. The sources were  $^{208}\text{Po}$ , alpha energy 5.114 MeV. The count rate of these sources was approximately 0.1 counts/second. A low voltage power supply produces the required operating voltages for the spectrometer including a -50V bias supply for the alpha detectors.

### 3.1.3 X-Ray Spectrometer

The X-Ray Spectrometer looks at induced radioactivity of the moon to determine the major elemental composition of the lunar surface. This is accomplished by measuring the x-ray fluorescence induced in the lunar surface by the incident solar radiation. The induced radiation is characteristic of the elemental composition and qualitative and semi-quantitative analysis can be derived.

The sensing elements are proportional counters. There are three gas filled proportional counters with an entrance window of .001" beryllium. Each counts individual x-ray photons for successive eight second intervals. The counters themselves are sensitive to x-rays in the range 1~10 keV. However, two of the counters contain a filter, one thin magnesium and the other aluminum, that reduces sensitivity of the counter to photons with an energy larger than the characteristic K absorption edge of the filter material by strongly absorbing the photons. Above 3 keV, the filters are essentially transparent again because the x-rays are more penetrating. The proportional counters also provide a certain degree of energy resolution. A count results in a pulsed signal whose amplitude is proportional to the photon energy. However, the resolution is rather broad typically about 30 - 40% at 2 keV.

A fourth proportional counter is used to monitor the solar x-ray radiation incident on the lunar surface. This counter also has a 1 mil beryllium window. However, the window area is much smaller as the solar flux is much greater than the fluorescing flux from the lunar surface.

Each proportional counter is connected to a charge sensitive preamplifier that converts the counter charge pulse into a voltage pulse. Pulse height analysis is then used to sort the x-ray

signals into seven energy bins between 0.7 and 3 keV, plus an eighth channel for higher energies.

Digital accumulators count the number of x-ray photons for each energy bin of each proportional counter. At eight second intervals the contents of these accumulators are transferred to output shift registers and the accumulators are reset to begin counting x-ray events in the succeeding eight second interval. The previous interval's data, now located in the shift registers, are readout to telemetry, eight bits each 100 ms.

The X-Ray Spectrometer incorporates a pulse shape discriminator designed to eliminate signals caused by incident gamma rays. The gamma rays typically have a longer ionization track in the proportional counter than x-rays and therefore produce an output pulse with a longer rise time at the preamplifier. This rise time difference is used to identify gamma rays. When one is detected, the pulse height analyzer and counter is disabled, preventing this false datum from being recorded in the PHA accumulators. However, the gamma ray flux is counted in a separate accumulator and telemetered back.

At 16 minute intervals, radioactive calibration sources are positioned in front of the lunar proportional counters for 64 seconds, thereby performing an end-to-end system calibration. The solar detector has a low activity fixed calibration source. At 8 hour intervals the energy range of one of the three lunar surface detector channels is shifted upwards by a factor of two (to 1.4 keV to 6 keV) for a period of two hours. This allows higher energy x-rays to be analyzed.

The X-Ray Spectrometer contains a temperature control system which prevents the temperature of the lunar proportional counters from falling below  $-20^{\circ}\text{C}$ . The Spectrometer also contains the necessary low and high voltage power supplies and voltage and temperature monitors.

#### 3. 1. 4 Ground Support Equipment (BTE)

The computerized Ground Support Equipment used a Nova minicomputer as the "executive" of a real-time automatic test and data acquisition system. GSE primary tasks were: (1) management and control of all peripheral equipment including a programmable pulse generator, digital plotter, 64 channel multiplexer and A/D converter, the "experiment-under-test," the ubiquitous ASR-33 teletype and an ultra-precise radioactive source positioning fixture; (2) data acquisition and management including data accumulation from both Alpha and X-Ray Spectrometers simultaneously, real-time calculation of assorted instrument parameters and analog data acquisition and limit checks; and (3) provision of an English language type man-machine interface requiring only a semi-skilled operator, a choice of either manual/keyboard test selection or a completely automatic "hands off" canned testing profile (See Fig 3-1 and 3-2).

The major considerations and constraints which helped to shape the BTE conceptual approach and configuration were:

- a. A very limited budget.
- b. At least one completely operational system ready for use in 90 days.
- c. Simulation of all spacecraft electrical interfaces including Power and Control, Timing and Telemetry.
- d. Provide data reduction, display and output for a very complex, highly multiplexed data stream which in effect service fourteen separate experiments simultaneously (fourteen detectors).
- e. Primary scientific data characterized by low event rates and statistical nature (requiring long accumulation times).

END ITEM SPECIFICATION

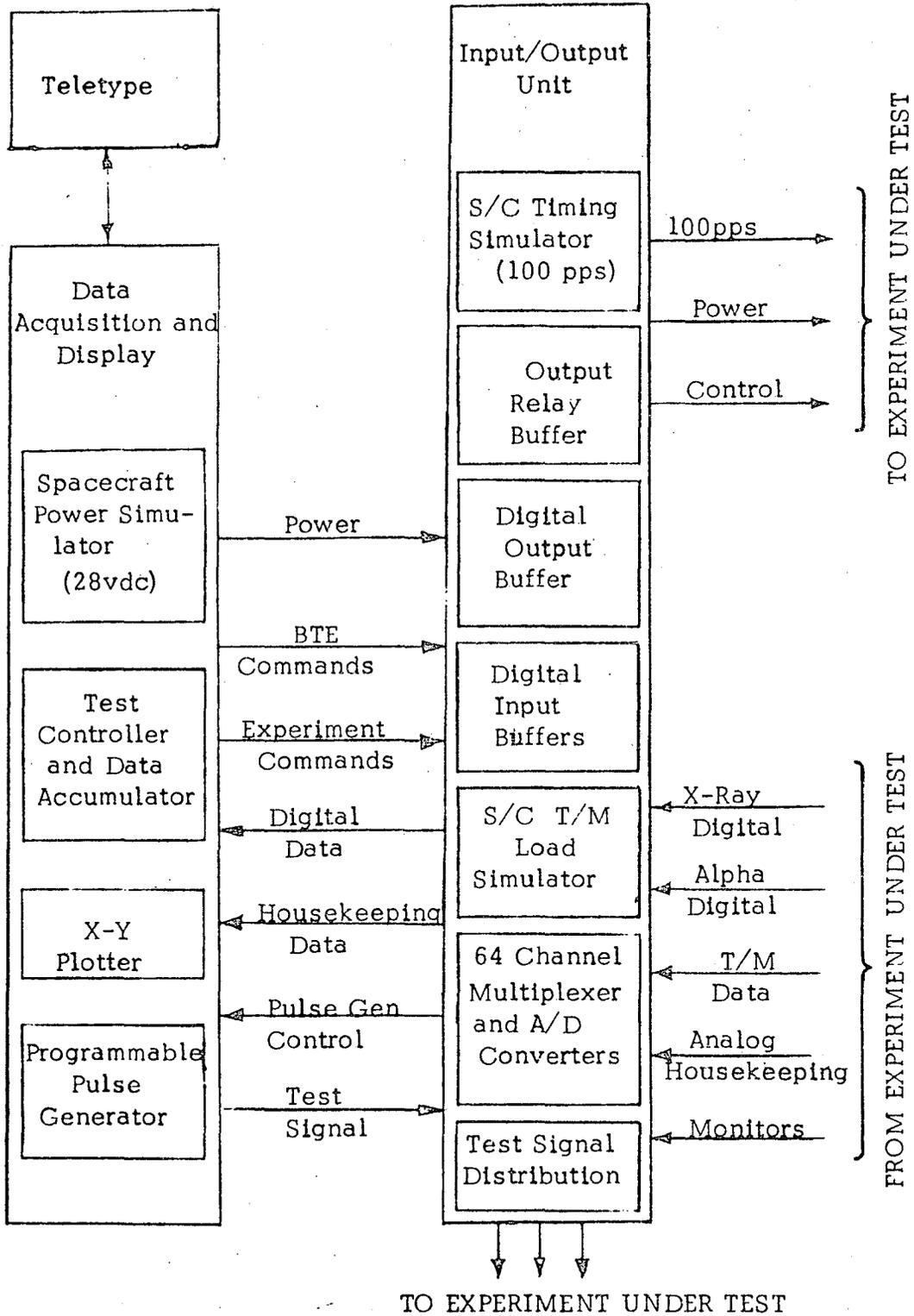


Figure 3-1. BTE Block Diagram



- f. Provide varying degrees of test support capability for six different experiment configurations from initial post manufacturing checkout to final prelaunch tests.

The computerized approach chosen offered many advantages:

- a. BTE hardware could be assembled from standard off-the-shelf components with little or no original design required.
- b. Many of the tasks could be accomplished in parallel, i. e. hardware procurement cycle and assembly with the design and generation of the software, etc.
- c. Because of the flexibility or adaptive nature provided by a software programmable computer, changes due to either experiment design modifications or test requirements could be expeditiously accommodated with minimum program impact. (An important consideration when the test support equipment must be designed before the experimental instrument itself.)
- d. The use of semi-skilled test operators which enabled the establishment of a large successful test crew rather quickly.

The versatility of this computerized approach can best be demonstrated by the following examples. The computerized approach accomplished more than AS&E originally had intended since the X-Ray Spectrometer was conceptually redesigned quite late in the program. However, because of the flexibility of the software programmable "executive," the change was accomplished with minimum impact on the delivery schedule and the scientific mission.

An additional unplanned task for the BTE was the control of a radioactive source positioning test fixture requiring the precise positioning ( $\pm .001"$ ) of 9 different radioactive sources at 26

different preselected locations within the field-of-view of the instrument while exposed to hard vacuum and four discreet temperatures. Although a hardwired controller could have accomplished the control task with an enormous **increase** in the time, the same "executive" undertook that task at the small cost of generating a relatively simple software routine.

In summary, the BTE fulfilled its intended function while satisfying extraordinary fiscal and schedule constraints. Several thousand hours of test data were accumulated from the four experimental instruments providing the scientists with rather intimate knowledge of instrument behavior and characteristics.

## 3.2 Hardware Design and Development

### 3.2.1 Alpha Spectrometer

The Alpha Spectrometer analyzes the energy of alpha particles with a high degree of resolution: Incident alpha particles are sorted into one of 128 distinct energy bins between 4.7 meV and 9.1 meV. To maintain the precision of this measurement, the gain of the entire analog signal channel must be very stable and the internal noise of the channel must be small.

The detector used for this application is a set of thin silicon surface barrier detectors. These are discussed more fully in Sections 3.1 and 3.3. Suffice to say here that their radioactive energy-to-charge "gain" is quite stable, being dictated by constants of nature, and that low noise was a major criterion in their procurement.

The alpha detectors operate into charge sensitive preamplifiers which convert the charge input from the detectors into voltage output. Stable charge-to-voltage gain is achieved in the CSPA section by use of

large amounts of negative feedback (open loop gain is approximately 30,000). This negative feedback forces the charge-to-voltage gain of the CSPA to be fixed only by the value of C8 (actual gain is given by the reciprocal of C8)). Capacitor C8 is a 1.5 pf precision, high reliability, glass capacitor. The voltage gain of the following voltage amplifier is similarly forced by negative feedback to be dependent only on the values of stable passive components, in this case four high reliability metal film resistors, R19, R23, R35 and R36. The noise performance of the complete preamplifier is set by the noise characteristic of the input FET, Q1. An ultra-low noise device, Texas Inst. SF9064, was selected to achieve the required low noise performance. As mentioned in Section 3.1.2, the outputs from the ten alpha detector preamps are summed to allow use of a single analog-to-digital converter (ADC). Prior to this step, each of the preamp outputs is passed through a biased amplifier having an equivalent bias offset of approximately 350 keV. Without this bias offset an output pulse from one preamp would be degraded by the noise of the other nine preamps. In both the biased amplifiers and the summing amplifier generous amounts of negative feedback are used to produce stable gains, and low noise transistors are used throughout to minimize signal-to-noise degradation. In addition, the frequency response of the analog signal channel is shaped to reduce the noise delivered to the ADC while minimally affecting the alpha event pulse shape. This filtering is secured with a three pole Bessel low pass filter and a single pole high pass filter.

Following the summing amplifier, the alpha event pulse goes to the analog-to-digital converter (ADC). Here, the requirements of stable gain and low noise are as stringent as before. However, in addition, the circuit must quantize the pulse height to nine bit accuracy.

As detailed in the preceding section, only the upper half of the digitized energy range is telemetered. The alpha energies of interest fall only in the upper half of the spectrometer energy range. Events in the lower half would be uninteresting background. To transmit such would be wasteful of telemetry time. Moreover, by transmitting only the upper half of the digitized energy range, the most significant bit (MSB) need not be telemetered as it must be a "one." This allows the instrument to digitize to a nine-bit accuracy while only transmitting eight bits. The MSB is used internally to identify desired data, enabling data transmission.

### 3.2.2 X-Ray Spectrometer

In the design of the X-Ray Spectrometer the prime considerations were good energy and spatial resolution and fast design "turn around" time due to the limited time scale of the program. Secondary considerations were low volume, low power consumption and low telemetry rates. The requirement for fast design "turn around" was met by using or modifying existing UHURU (SAS-A) designs for much of the spectrometer.

The charge sensitive preamplifier in the "front end" is one example of a SAS-A design which was used on the Lunar Spectrometer. This design is shown in Figure 3-3. Transistors Q1, Q2 and Q3 comprise the charge sensitive loop. Feedback from the emitter of Q3 to the base of Q2 holds the gain of the differential amp (Q1, Q2) at unity. Therefore, the only device having positive gain is Q3, which is designed for very high gain. By placing all the open loop gain in one device, loop stability is simplified (no stabilizing networks are required). Capacitor C5 and resistor R9 close the loop and provide the desired charge sensitive performance. Transistors Q4 and Q5 make up a post amplifier and provide the required voltage gain. The whole circuit provides the required gain

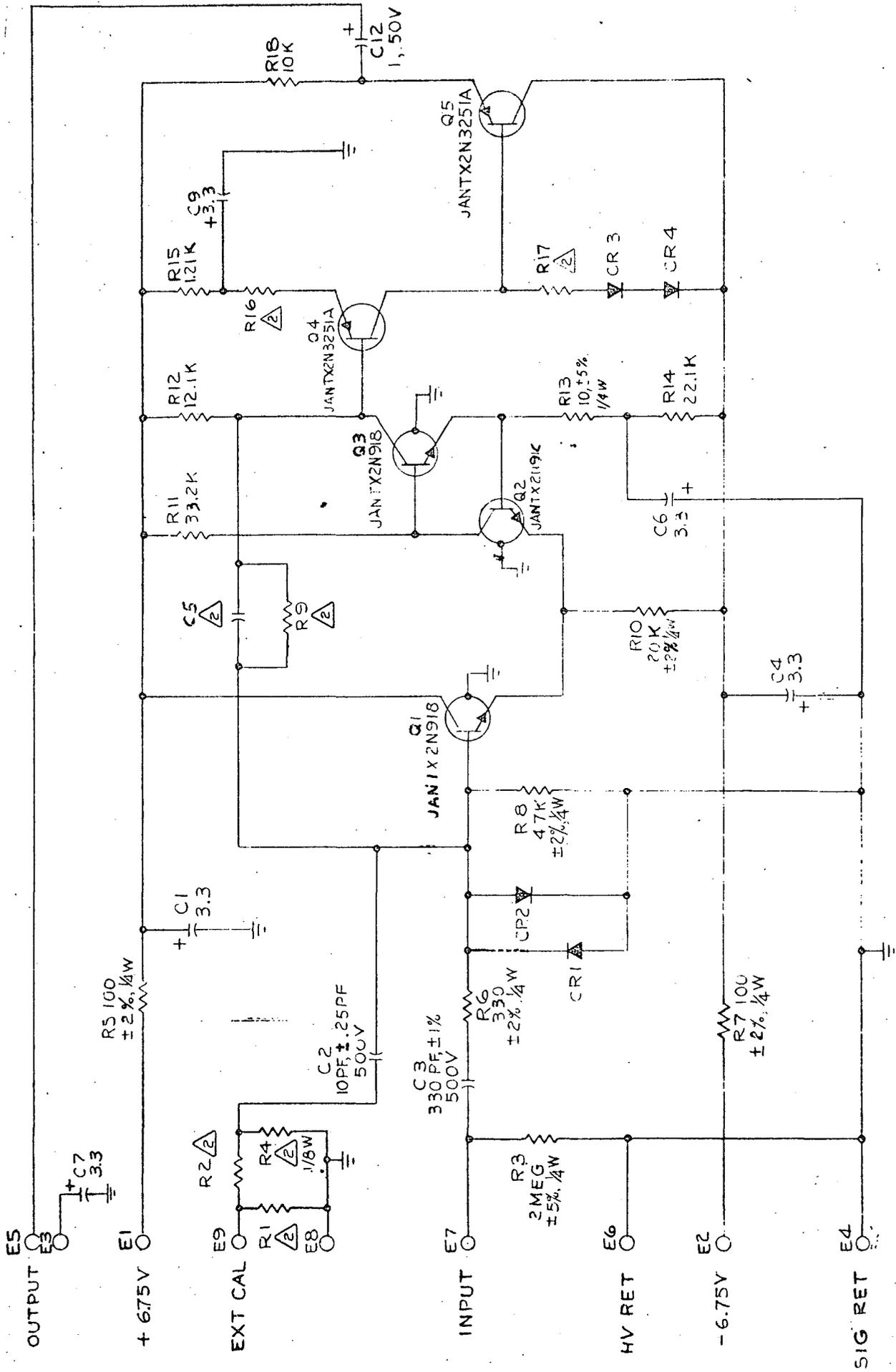


Figure 3-3. Proportional Counter Preamplifier Schematic

with good rise time (needed for the succeeding pulse shape discrimination) and low current drain.

To discriminate against Gamma events, each of the three Lunar X-Ray signal channels has a Pulse Shape Discriminator which measures the pulse rise time and produces a veto signal if the rise time is excessive thereby indicating a Gamma pulse rather than an x-ray was received. The PSD Veto signal inhibits further analysis of the event. PSD Vetoes are counted and Telemetered for each of the three Lunar Detectors. The pulse shape discriminator distinguishes between X-ray and Gamma pulses by measuring their rise time. A Gamma-ray has a longer ionization time in the Proportional Counter thereby producing a pulse with a longer rise time. The pulse shape discriminator functional block diagram is shown in Figure 3-4 and the timing in Figure 3-5. To measure pulse rise time, the negative going pulse is differentiated and the negative portion of this signal, which occurs during the pulse rise time, is detected in the Zero Crossing Detector.

The pulse is also amplified in an Overdriven Amplifier and the output triggers a Time Subtraction One Shot. The One Shot output is logically time subtracted from the Zero Crossing Detector output to obtain the Ramp Gate. The ramp output of the Ramp Generator is compared with a set reference in the Discriminator output which triggers a One Shot to produce the PSD Veto output signal. The Time Subtraction One Shot is set for 30 nsec, and the Discriminator Reference Voltage is set to veto pulses that have rise times greater than approximately 500 nsec.

The bulk of the X-Ray Spectrometer circuitry is digital and it is in this area that the concern for packaging volume was directed. The largest part digital circuitry is the accumulator/shift register group. This is composed of 32 16-bit accumulators and 32 20-bit





shift registers. The accumulators sum up the number of x-rays in each of eight energy bins received by each of four x-ray detectors. Once every T/M frame the contents of the accumulators, plus additional housekeeping data, are strobed into the shift registers where the data is sequentially shifted out to telemetry. This large amount of circuitry was packaged on ten thin digital modules. The tight density was made possible by extensive use of MSI logic (TI/SN54L93 and SN54L95) and by skillful packaging design.

### 3.3 Major Hardware Problems

#### 3.3.1 Alpha Detectors

As a result of a large rejection rate of the silicon surface barrier detectors used in the Alpha Spectrometer, a review of the detector procurement cycle was conducted. This review included the complete manufacturing cycle, in-process fabrication, test and end item use. A failure history was compiled and included analyses of failed detectors to determine failure modes and their causes. Initial analyses resulted in incorporating photosensitivity and burn-in testing, as criteria for detector acceptability, and in modifying the manufacturing process to allow the metal electrodes to be deposited in a single-step rather than in a two-step operation. This process change was initiated towards the end of the procurement cycle. For flight hardware, only detectors that were made in this way, and which are subjected to a burn-in cycle will be used.

A complete investigation of this problem was conducted by AS&E and a detailed report, "Reliability Evaluation of Silicon Surface Barrier Detectors," ASE-2626, was submitted on 22 February 1971.

#### 3.3.2 X-Ray Calibration Assembly

3.3.2.1 Source Bar - This holds the x-ray calibration sources

and is mounted so that it can be rotated in order to move the sources into, or out of, the calibration position.

Failures of this assembly during acceptance testing of the Qualification Model led to a redesign of the assembly as follows:

- a. The source bar stiffness was increased.
- b. The drive gear train was changed from aluminum to stainless steel, the diametral pitch was changed from 2P to 48P; and full gears, rather than segmented, are now in use.
- c. Source bar balancing provisions were incorporated into the installation procedure.

3.3.2.2 Rotary Solenoid - This is used to drive the Source Bar into the calibration position. It has been redesigned to include a cam follower spring. Prior to this change, the device was position sensitive.

The flight units are equipped with the redesigned calibration assembly.

### 3.3.3 EMI

During EMI testing of the Qualification Model the experiment failed to pass the transient susceptibility and conducted interference tests. To remedy the conducted interference failure, an EMI filter was designed and after tests proved its effectiveness it was installed. Failure of the transient susceptibility test was traced to inductive coupling in x-ray detector channel 2 between the heater control thermistor and the preamplifier. The thermistor was relocated and when the test was repeated the results were acceptable. The drawing package was updated to include both of these modifications which are effective for both flight models.

### 3.3.4 Z-93 Paint

After acceptance testing of the Qualification Model, the Z-93 paint

was observed to have flaked over approximately 10% of the Alpha Sensor Assembly, 1.0% of the main frame and 1.0% of the Solar Monitor Assembly.

A consultant from the Illinois Institute of Technology Research Institute was employed to investigate the problem and to provide a solution. The investigation resulted in a new definition of Z-93 coating thickness, surface finish, and binder type and ratio. The application techniques were examined also, and new procedures generated to reflect the results of the investigation.

### 3.3.5 X-Ray Processor Analog Module A21

The noise sensitivity of this module originally was too high. As a result of failures during Acceptance Testing of the Flight 1 model, the clock input buffer was made less sensitive by replacing resistor R-24 with capacitor C10 (drawing 132-544-4). This change was effective on the Qualification Model and Flights 1 and 2. After this change was incorporated, synchronization errors were virtually eliminated.

### 3.3.6 Solar Monitor Assembly Collimator Plate

During Qualification Testing of the Qualification Model the SMA spectral range was found to be out of tolerance. An investigation of this failure showed that it was caused by contamination of the anode wire by negative ions. This condition is inherent in this type of counter, is cumulative over time, and is a function of the flux density of the incoming particles. This condition was alleviated by changing the viewing aperture from a circle to a long slit with the same area. This allows the flux of the incoming particles to be distributed over a larger anode area. This was accomplished by redesigning the collimator plate (drawing 132-761). The effectivity of the change is the Qualification and both flight models.

## 4.0 MAJOR TEST PROGRAMS

### 4.1 Design and Development Tests

The following test reports describe in detail the development test effort undertaken to explore the structural integrity of the mechanical design concepts and detail of various mechanical system elements.

The first report discusses vibration tests of Silicon Surface Barrier Alpha Detector exposed to 2 minutes of 41.4 g's rms overall random vibration in each of three mutually perpendicular axes. The test established the capability of this large area detector to successfully satisfy system vibration requirements.

The second and third reports describe vibration tests of the SPA and SMA Mass Mockups. These tests were undertaken to verify that the design of both structures would withstand the anticipated Service Module vibration environment as well as to verify response levels at key locations within both structures. The test results indicated certain deficiencies and corrective actions which are described in detail within each respective report.

The fourth test report describes tests of the X-ray Calibration Assembly which was exposed to three different profiles in each of three mutually perpendicular axes. Test results indicated the ability of the Calibration Assembly to survive the anticipated vibration environment.

#### 4.1.1 Alpha Detector Test

Test Date: 25 June 1970

Test Facility: Acton Environmental Labs, Acton, Mass.

Test Equipment: Ling A300 Shaker System with  
Ling A249 Shaker Amplifiers

Test Items: Six ORTEC Silicon Surface Barrier  
Alpha Detectors Model # B-055-300-100

Serial #'s: 10-180A  
10-183A  
10-200A  
10-67A  
10-196A  
10-176A

Test Procedure:

The six alpha detectors were mounted to AS&E vibration test fixture SK132-305 via #2-56 steel screws. The alpha detectors were then subjected to the random vibration test schedule listed below (see Figure 4-1).

Alpha Detector Random Vibration Test Schedule

<u>Axis</u>	<u>Frequency (HZ)</u>	<u>Level (g<sup>2</sup>/HZ)</u>
X, Y, Z	20 - 100	+11 db/oct.
	100 - 200	6.75
	200 - 400	-15 db/oct.
	400 - 2000	0.225

Overall g's rms: 41.4

Test Duration: 2 minutes each axis

Test Results

Each of the six alpha detectors was visually inspected for mechanical failure after vibration testing. No evidence of cracking or permanent deformation was found.

Test Conclusions

It may be concluded that the Lunar Alpha Detectors are capable of

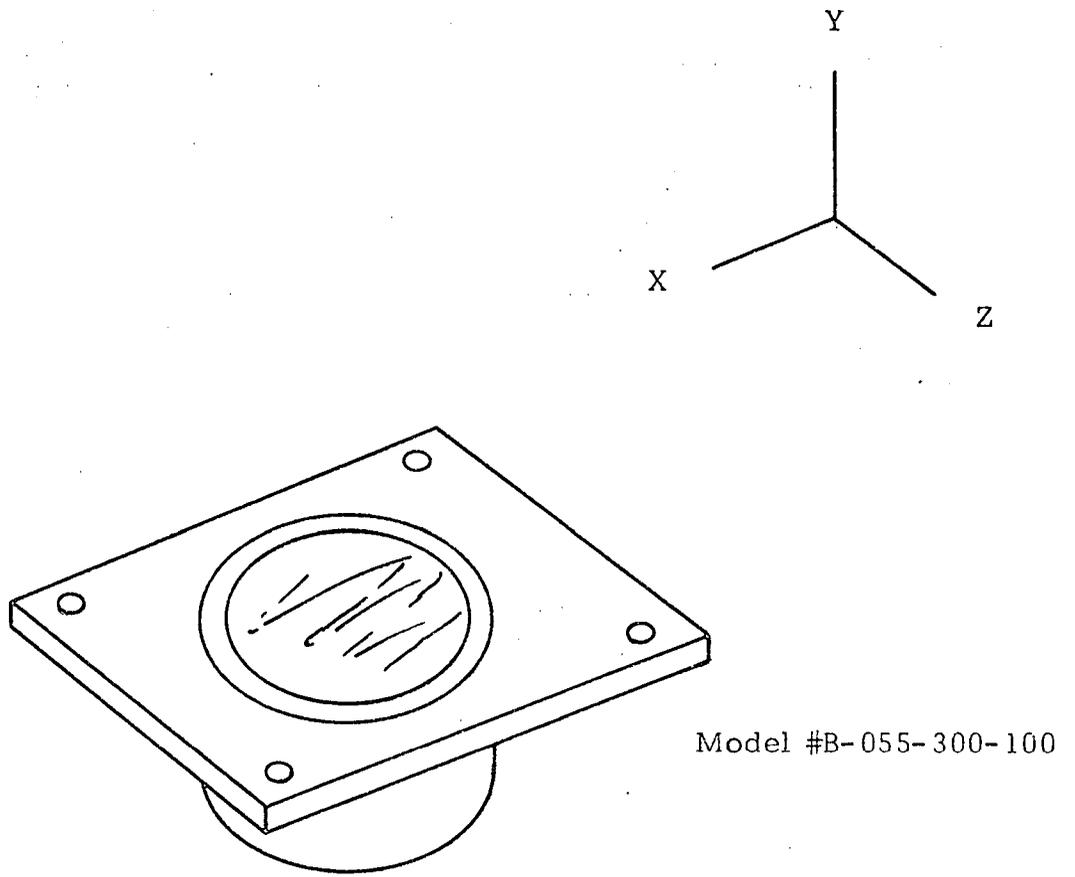


Figure 4-1. Alpha Detector Axes Orientation

mechanically surviving the vibration environment of their procurement specification (S132-105). It is also concluded that the "out of planeness" of the detector attachment surfaces provides an environment in which a detector casing failure may occur during vibration (such as occurred during acceptance testing of the Prototype SPA), or for that matter, merely on assembly.

4.1.2 Engineering Vibration Test for the X-Ray Solar Monitor Mass Mockup Assembly

4.1.2.1 Test Objectives - The primary objective of this test was to determine the capability of the X-Ray Solar Monitor Mass Mockup Assembly (SMA) to withstand structurally the expected vibration environments within the APOLLO SIM. The secondary objective was to collect response data in order to correlate it with existing procurement specification vibration test levels.

4.1.2.2 Summary

a. Structural Integrity

The X-Ray Solar Monitor Mass Mockup Assembly (SMA) was subjected to Apollo SIM vibration environments at Acton Labs on January 20 and 23, 1970. The assembly developed fatigue cracks toward the end of the test program which were not severe enough to halt testing. In the judgement of the writers, the present SMA design is considered capable of meeting the requirements without further testing for the following reasons:

1. The test durations employed were excessive thus providing an environment conducive to fatigue cracking.
2. The areas in which fatigue cracks occurred have

since been properly strengthened by the addition of doublers. The appropriate changes have been incorporated in the SMA design.

b. Component Vibration Response

The vibration response levels at the Analog and Digital Modules and Preamplifier were found to lie within their design criteria. The High Voltage Power Supply and the X-Ray Proportional Counter Z axis vibration response levels exceeded the design criteria. Those items will be vibration tested (in addition to vendor testing to the design criteria) to their respective Z axes SMA vibration response levels in order that their capability to meet them is established.

4.1.2.3 Conclusions

a. Structural Integrity

Fatigue cracks approximately 1/4 inch long were observed in the sheet metal portion of the main structure at the conclusion of the second to last vibration test. Testing was carried on to completion with some additional crack propagation observed. Shortly after completion of the vibration test program it was learned from North American that the test durations employed were excessive. The areas in which fatigue cracks appeared have been, however, properly strengthened by the addition of doublers and the appropriate changes incorporated in the X-Ray Solar Monitor structural design in order

to remove any doubt as to its structural integrity. It is therefore concluded that structural integrity of the X-Ray Solar Monitor is now sound.

b. Component Vibration Response

Z axis vibration testing induced the most severe accelerometer response levels for all the Solar Monitor Assembly components.

4. 1. 3 Engineering Vibration Test for the Alpha/X-Ray Spectrometer (SPA) Mass Mockup Assembly

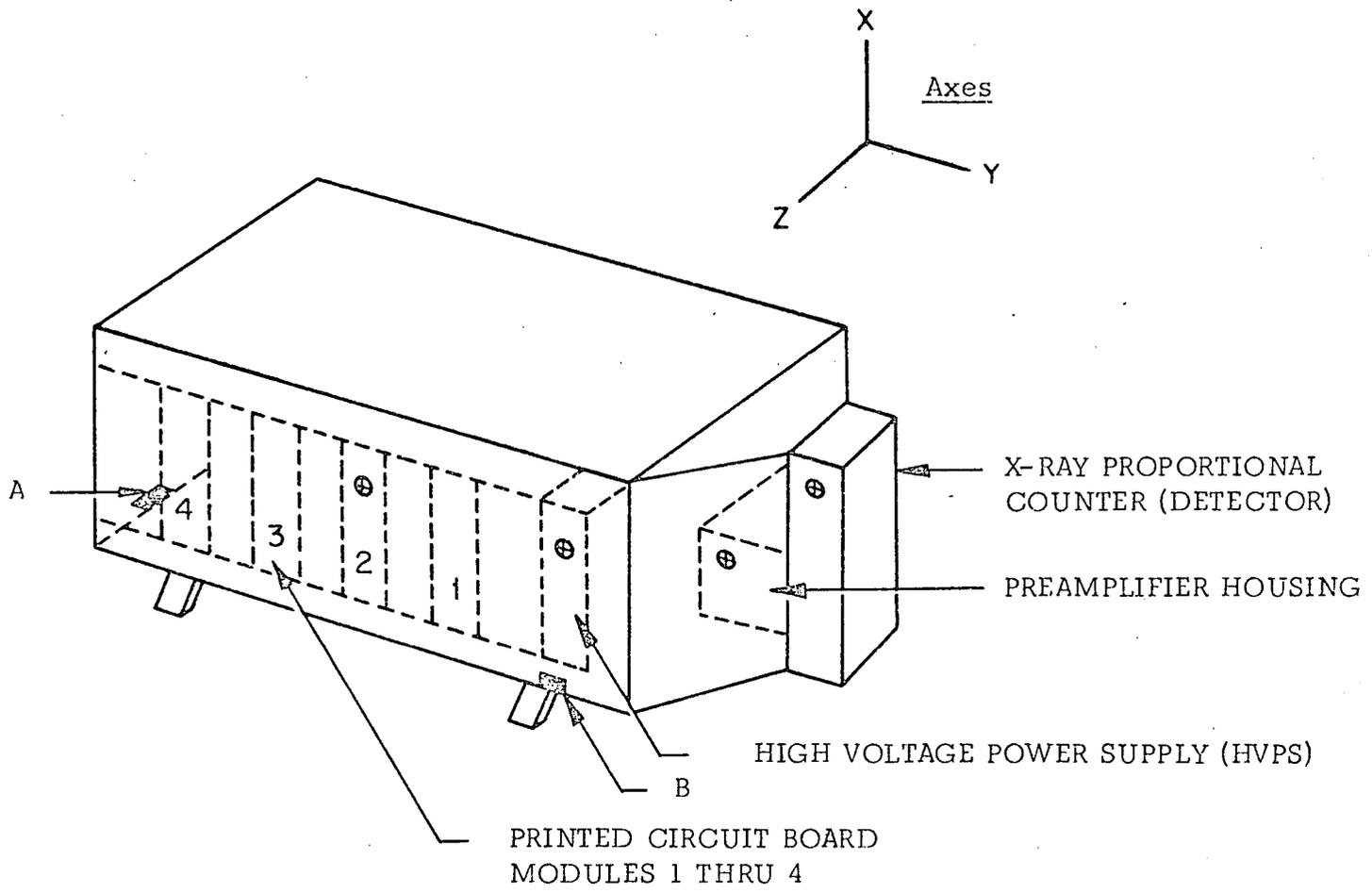
4. 1. 3. 1 Test Objectives - The primary objective of this test was to determine the capability of the Alpha/X-Ray Spectrometer Mass Mockup Assembly (SPA) to withstand structurally the expected vibration environments within the Apollo SIM. The secondary objective was to collect response data in order to correlate it with existing procurement specification vibration test levels (see Figure 4-2).

4. 1. 3. 2 Summary

a. Structural Integrity

The SPA Mass Mockup Assembly was subjected to Apollo SIM vibration environments at Acton Environmental Labs, Inc. on February 10 through 13, 1970. All tests were completed with the exceptions of the +4 db, 10 second portions.

Excessive specimen and fixture "noise" produced frequent shaker shutdown during the latter portion of these two tests. A new, "noiseless" fixture (SK132-3134) has been designed and built for future Z and Y axis SPA testing.



⊕ Indicates approximate accelerometer locations

Figure 4-2. X-Ray Solar Monitor Mass Mockup Assembly

The only structural failure appeared in the brazed connection between the X-Ray Detector Assembly collimator and its support structure. The brazed connection was found to be of poor quality (porous, sharp fillet radii, etc.). The collimator support structure was found to be unnecessarily flexible and tended to deform the collimator connection under its own relative motion. No cracking, or permanent deformation of any type was noted throughout the remainder of the SPA Mass Mockup Assembly upon completion of all testing.

b. Component Vibration Response

The vibration response levels of the SPA Mass Mockup Assembly components, with the exception of the Low Voltage Power Supply, were all found to lie within their respective procurement specification criteria.

4.1.3.3 Conclusions

a. Structural Integrity

The present SPA design is considered capable of meeting the requirements without further developing testing for the following reasons:

1. The brazed connection between the X-Ray Detector Assembly collimator and its support structure in which cracking occurred was found to be of poor quality (porous, sharp fillet radii, etc.). More care will be taken in future SPA models in this area. The collimator support structure, which offered only a

flexible support to the brazed connection has been stiffened and the appropriate changes incorporated into the SPA design.

2. The SPA Mass Mockup Assembly survived the complete X axis vibration testing called for. This is significant since the X axis is the most critical from a structural analysis point of view. The fact that the SPA Mass Mockup Assembly survived the complete X axis testing provides a high degree of confidence in its ability to survive the Apollo SIM vibration environments. Calculated vibration response levels for the +4 db, 10 second portion of Z and Y axis tests show lower PSD and overall rms levels than the sinusoidal equivalent 50 g loading called for by the SPA design.

b. Component Vibration Response

The vibration response levels of the SPA Mass Mockup Assembly components, with the exception of the Low Voltage Power Supply, were all found to lie within their respective procurement specification criteria and it is therefore concluded that their procurement specification vibration criteria are valid.

4.1.4 Engineering Vibration Test for the X-Ray Calibration Assembly Engineering Model (dwg 132-512 Rev. C)

4.1.4.1 Test Objective - The objective of this test was to determine

the capability of the X-Ray Calibration Assembly (Dwg. 132-512, Rev. C) to withstand the expected vibration environments within the Apollo SIM and to function satisfactorily thereafter.

4.1.4.2 Test Summary - The X-Ray Calibration Assembly was subjected to expected Apollo SIM vibration environments at Acton Environmental Labs, Inc. on October 3, 1970. The assembly was observed during each vibration test and no excessive relative motion was noted. Following each vibration test in each axis the assembly was electrically functioned and was observed to function in a satisfactory manner.

4.1.4.3 Test Conclusions - The X-Ray Calibration Assembly design per Dwg. 132-512 Rev. C is capable of withstanding the expected vibration environments within the Apollo SIM and function satisfactorily thereafter.

#### 4.2 ATEE Laboratory Testing

From 13 July 1970 through 25 September 1970, AS&E supported an electrical integration effort of the prototype instrument with other system elements of the SIM Bay.

On 22 July the Post-Transportation and Pre-Integration tests were completed by the field team located in the ATEE Lab at NAR, Downey, California. Because of power supply delivery problems, the Post-Transportation test was performed using a power supply simulator which was subsequently replaced by prototype power supplies prior to the start of the Pre-Integration test profile.

A significant on-going problem was that of Data Reduction using the NAR Ground Station. Much effort was expended in considering alternatives as well as supporting the software development activity and assisting in the debugging of same. The cause for great concern

was that no Alpha/X-ray data would be available to evaluate results of the integrated testing.

Following Spectrometer installation in the SIM a connector fit problem was discovered manifesting itself by the inability of connectors J1 and J4 to lock. A temporary repair was implemented on the prototype and appropriate changes were made to subsequent units.

A second Pre-Installation test was performed after the prototype low voltage power supplies were returned from Time Zero where certain of the voltages had been recalibrated. This test activity concluded on 7 August 1970.

The next test, a Partial Integration Test, exploring the Spectrometer/Spacecraft simulator interface and inter-experiment interference was marred by problems of primary power failure, noisy spacecraft timing and scientific data system problems. This test activity concluded 28 August 1970.

The next scheduled activities were the verification of experiment data through the Scientific Data System and the performance of an Integrated System test with the Scientific Data System and Ground Station. The Spectrometer data processed through the Scientific Data System was stripped out serially (data reduction software not available yet) and revealed a transposition. The experiment data was being read out backwards. All test activity terminated while NAR investigated the Scientific Data System.

Integrated testing continued with the performance of three tests:

Sequence I: Alpha/X-ray Spectrometer integrated with ATEE Lab SIM simulator and Scientific Data System and no other experiments energized.

Sequence II: Alpha/X-ray Spectrometer integrated with

ATEE Lab SIM simulator and Scientific Data System and all experiments energized simultaneously.

Sequence III: A compressed mission profile performed in the same configuration as Sequences I and II but with no BTE used for data reduction.

Integrated testing concluded successfully with knowledge of some interface wiring problems, enough of the reduced data to verify proper experiment operation and the identification of a 2% crosstalk problem between the Pan Camera torque drive circuits and Alpha/X-ray housekeeping functions.

ATEE Lab testing concluded with the successful performance of a Power Profile test and a final attempt to clean up the Ground Station/Data Processing software. The detailed results of ATEE Lab testing are, of course, described in a NAR Test Report.

#### 4.3 Qualification Testing

The Qualification Test Program for the Alpha/X-ray Spectrometers occurred in two stages; an initial Flight Qualification Test Program followed by a Delta Qualification Test Program.

The Flight Qualification Test profile consisted of Acoustic Noise, Vibration, Electromagnetic Compatibility and Temperature-Vacuum tests and was performed between 19 November 1970 and 8 January 1971. The detailed results of this test sequence are contained in ASE-2640, Volume I, Qualification Test Report.

Following the addition of EMI filters and modification of some main harness wire routing, the instrument was subjected to a Delta Qualification Test Program composed of Electromagnetic Compatibility, Vibration and Temperature-Vacuum Tests. This test profile was undertaken to validate the flight integrity of the modification and new elements added to the system as a result of

the initial Qualification Test profile. The detailed results of the Delta Qualification Test sequence are contained in ASE-2640, Volume 2, Delta Qualification Test Report.

Both Test Programs were completed successfully and expeditiously as evidenced by the successful Apollo 15 mission.

## 5.0 RELIABILITY, QUALITY ASSURANCE AND SAFETY

### 5.1 Reliability

#### 5.1.1 Alpha Detectors

A major area of concern of the Reliability Department during this program was the Alpha Detectors (discussed in Section 3.0).

The steps taken to maintain this device as a high reliability part, in addition to repeated consultations with the vendor and several audits of his manufacturing process, included the following:

- a. Special handling instructions were written for use by AS&E personnel. These were discussed in meetings in which the Project Scientist presented the instructions to members of the manufacturing facility and emphasized the necessity for adherence to them.
- b. All installations of the detectors, or work on a completed assembly in which a detector was installed was performed on a Laminar Flow Bench.
- c. A special tool was designed to be used for the installation of sources in order to prevent damage to a detector when sources were installed or removed.
- d. After acceptance, all detectors were kept in bonded stores until they were needed.
- e. Burn-in of the Alpha detector before and after installation in a module was initiated.

The Reliability Program has been implemented throughout the life of the contract by a Reliability Project Engineer assigned permanently to the program.

#### 5.1.2 False X-Ray Data Outputs

During pre-launch testing of Flight model 2A at KSC, the CSM telemetry system recorded false X-Ray data. The false data was found to be caused by fast rising current transients on the X-Ray

digital output lines. These output lines are connected (in parallel, effectively) to both the BTE connector and to the CSM telemetry connector on the SPA. The transients coupled noise into the chassis ground system which conducted it to the output of the three lunar detector preamplifiers. This noise then was processed as X-Ray events would be and appeared as false X-Ray data in the telemetry system.

The fault was corrected by inserting a 1000 ohm resistor into each of the eight digital lines to the telemetry connector, and also inserting the same resistor values into each of the eight lines to the BTE connector. These resistors act to decrease the coupling to the chassis ground system.

This modification was tested by breadboarding the proposed change and connecting it into the Prototype and Qualification models. Upon successfully concluding the tests the change was implemented for the Flight 2A model.

A detailed discussion of this change is contained in AS&E's "Contract Change Proposal for Modification of X-Ray Spectrometer to Correct for False X-Ray Data Outputs" CCN #28, document number ASE-2858, contract NAS9-9983. The initial report of failure is contained in NASA DR0016.

## 5.2 Parts and Materials Lists

The parts and materials program has been implemented through the use of controls exercised by the Reliability Project Engineer:

- a. Review of all purchase requisitions to ensure that only approved parts were purchased.
- b. Review of all drawings to ascertain that parts and materials used were only those that appear on the approved parts and materials list.

- c. Preparation of screening specifications for parts and materials when required.

Parts and Materials lists were submitted and approved early in the program. They were updated as required, and each new addition reported to MSC for approval.

### 5.3 Safety Program

- a. Rupture of X-Ray Source

During Acceptance Testing of the Flight 2 Model, double peaks were observed in the Alpha spectra. The cause of this failure was traced to the on-board calibration source for X-Ray counter 2. The seal at the rear of this source was found to be defective and this permitted polonium to "leak". The resulting migration of particles to the Alpha spectrometer allowed it to detect the polonium, hence the second peak.

The following steps were taken to ascertain the health and equipment hazards that may have been caused by this failure.

1. A radiation test of the spectrometer was conducted. The results were negative because of the minute size of the particles.
2. An attempt to clean the area with solvents failed because of the particle size.
3. The incoming inspection procedure for the sources was updated to include an examination of the rear of the sources as well as to record the count rate from the front.
4. The Project Scientist determined that by flight time the amount of contamination that was observed at the time of failure would be decreased by a factor of 3 due to its natural decay process; further, he ascertained that neither of the spectrometers nor other experiments in the spacecraft would be affected.

b. Contamination of Alpha Detectors

A 48 hour burn-in at hard vacuum of Alpha Sensor Assembly (132-503, S/N 7352) was conducted after the assembly had been retrofitted per ECP's 18 and 21. After this test was completed, a film of liquid was observed on the front surface of the assembly. The liquid was analyzed and found to be DOW Corning 706 a silicon fluid used in the vacuum chamber diffusion pump. Subsequently, the investigation disclosed that an improperly seated High Vacuum Valve had permitted the fluid to backstream into the chamber during the period when the chamber was in the process of returning to room ambient temperature. The following tasks were conducted in order to protect the integrity of the assembly:

1. The ten 520 modules and the two all purpose modules were pulled from the sensor assembly frame. Visual inspection of the frame with black light and general light revealed a silicon fluid film on the Birtcher module slides and horizontal frame members.
2. The 132-520 module top covers were removed. Each module has two vent holes in the top covers. The only two modules exposed (top cover) are the modules A1 and A6 (top two modules). These two modules were the only two that exhibited a fluid film on the bottom of their cases. All 520 module collimator plates were removed and inspected. All exhibited the fluid film on the inner portion of the cylindrical collimator. The detector surfaces were visually inspected with the collimator plate off. All detectors exhibited a fluid film on the circular epoxy portion of the detector from about 4 o'clock to 8 o'clock (held horizontally). The G-11 mounting block also exhibited the same fluid films as did the detector epoxy ring. Although the fluid film could not be seen on the detector surfaces, (inspected under black and normal light 1X and 10X magnification) it is unlikely that this surface escaped the Dow Corning 706 Silicon fluid. This silicon is

stable and is not chemically reactive and should not deteriorate the reliability of the Alpha detectors.

3. All portions of the Sensor frame and modules that exhibited the fluid, with the exception of the detector surface, were wiped clean with cotton swabs and Kim-wipes. The Alpha Sensor Assembly was assembled, and the test continued. Prior to continuation of the Alpha alignment test, and after the unit had been cleaned, the Sensor Assembly was placed in a chamber and operated in a vacuum of  $10^{-8}$  torr and a temperature of 120°F for a period of 48 hours. At the end of that time, the resolution of the detectors was measured and found to be acceptable. After this was done, the Sensor Assembly was aligned, installed in the system in preparation for the Flight 2A Acceptance Test  
132-140/2 Rev. G.

c. Preventive Action at KSC

1. RTV Contamination Risk - In July, 1971, the AS&E field office at KSC learned that North American planned to use a compound designated as RTV 102 around the access port on the SIM bay door. AS&E investigated this compound and discovered that it did not comply with the outgassing (T) and volatile condensable material (VCM) requirements imposed on AS&E by MSC. Since AS&E had previously established a relationship between contamination on the surface of the Alpha detectors and operational failures of these devices, AS&E informed MSC that use of RTV102 would risk damage to the Alpha Spectrometer. In addition, AS&E suggested that North American use one of two recommended adhesives, either RTV 566 A/B or RTV 93-500 in place of RTV 102.
2. Exhaust Contamination Near the Spectrometer - During the demonstration count down, AS&E field personnel discovered that a workman on the launch gantry had placed a motor so that exhaust fumes would completely cover the exposed (i. e. X-ray and Alpha detectors) portion of the Spectrometer. Since this would most certainly result in contamination of these devices, and since AS&E had previously demonstrated a correlation between contamination of the Alpha detector and detector failures, the countdown was held until the motor could be moved and the area properly ventilated.

## 6.0 SUBCONTRACT MANAGEMENT

### 6.1 AS&E Subcontract Management Plan

The following is an excerpt from the AS&E Subcontracts Management Plan in effect during the period in which most of the major subcontracts on the Lunar Spectrometer Program were initiated. Since that time, AS&E has expanded its subcontracts department and now utilizes the service of a full-time Senior Subcontracts Administrator. AS&E has further, evolved a new subcontracts management plan that reflects more closely the ever increasing controls required to properly manage a large subcontract.

Experience on the Lunar Spectrometer program will be utilized in the management of larger, more complex space programs, envisioned for the future.

#### 6.1.1 Scope

##### a. Purpose

The purpose of this plan is to identify an organization within the Apollo Lunar Orbiter Program Office with the responsibility and authority for subcontractor management. This plan identifies the procedure used by this organization for procurement of all major hardware items, and to control its subcontractors on the Apollo Lunar Program under Contracts NAS9-9982 and NAS9-9983.

##### b. Objective

The objective of the plan is to assure timely deliver, at minimum costs, of subcontracted hardware which meets the specified design and quality assurance requirements.

#### 6.1.2 Reference Documents

##### NASA - MSC

Contract NAS9-9982

Contract NAS9-9983

##### AS&E

Purchase Order Form

Purchasing Procedures Manual

### 6.1.3 Definitions

Subcontracts: A contract placed with a vendor or subcontractor for the procurement of hardware and/or services.

a) in the value of \$5000 or more, firm fixed price or CPFF, that is procured to an AS&E generated technical specification and/or drawing.

b) in the value of \$25,000 or more, firm fixed price, as an off-the-shelf item or to a standard manufacturer production specification.

Purchase Order: An order placed for hardware and/or services.

a) less than \$25,000 firm fixed price as an off-the-shelf item or to a standard manufacturer production specification.

b) in value of less than \$5000 firm fixed price that is procured to an AS&E generated specification and/or drawing.

Subcontractor: Any manufacturer and/or seller supplying items under a subcontract (usually the term subcontractor is used in conjunction with the purchase of an item associated with high dollar value or an AS&E generated specification and/or drawing).

Supplier (Vendor): Any manufacturer and/or seller supplying items under a purchase order (usually used in association with minor procurements or those that represent an off-the-shelf item).

### 6.1.4 Management

#### a. Policy

The Apollo Lunar Orbiter Program Manager has designated as an integral part of the Program Office, a Manager for Subcontracts. The position of Manager for Subcontracts, involves the following responsibility and authority.

Responsibility - The Manager of Subcontracts is responsible for the program management for all facets of each of the Lunar Subcontracts and Procurements. It will be his responsibility to be constantly aware of progress-to-date and problems (both real and potential) on all procurements. He shall advise the Program Manager on these matters and shall make recommendations, if necessary, concerning courses of action.

Authority - His authority is the same as that normally associated with the position of Program Manager. He shall take whatever steps necessary within the scope of the respective subcontracts to insure that all requirements are met. If actions outside the scope of subcontracts must be taken, he shall consult with the Program Manager.

b. Organization

An organization chart for the Apollo Lunar Program Office is shown in Figure 6-1. The Manager for Subcontracts is a member of the Program Office, and has access to the technical disciplines, with Contracts and Purchasing, representatives reporting directly to him, for support in the technical and contractual monitoring of subcontracts and procurements. The organizational structure of this support is also shown in Figure 6-1.

6.1.5 Procedures and Controls

a. Subcontracts Procedure

Contract considerations for "make-or-buy" decisions are evaluated by the Program Office. When a buy decision is made, a technical specification and/or drawing is prepared or defined as a requirement by the responsible technical organization and in accordance with AS&E internal procedure.

A requisition for the items with a technical procurement specification and/or drawing and, where required, a clarifying Statement of Work is issued for approval. The approval requirements for requisitions are established by the Director of Programs by internal procedures.

A properly signed purchase requisition and applicable supporting documentation provides the subcontracts group within the Apollo Program Office the authority to commit the company to a legal purchase order. The purchase order is executed in accordance with the applicable contract requirements and existing American Science & Engineering purchasing procedure.

b. Vendor Procurement Procedure

The procedure for standard supplier items requires the preparation of a purchase requisition with the necessary approvals by the Director of Programs, as above.

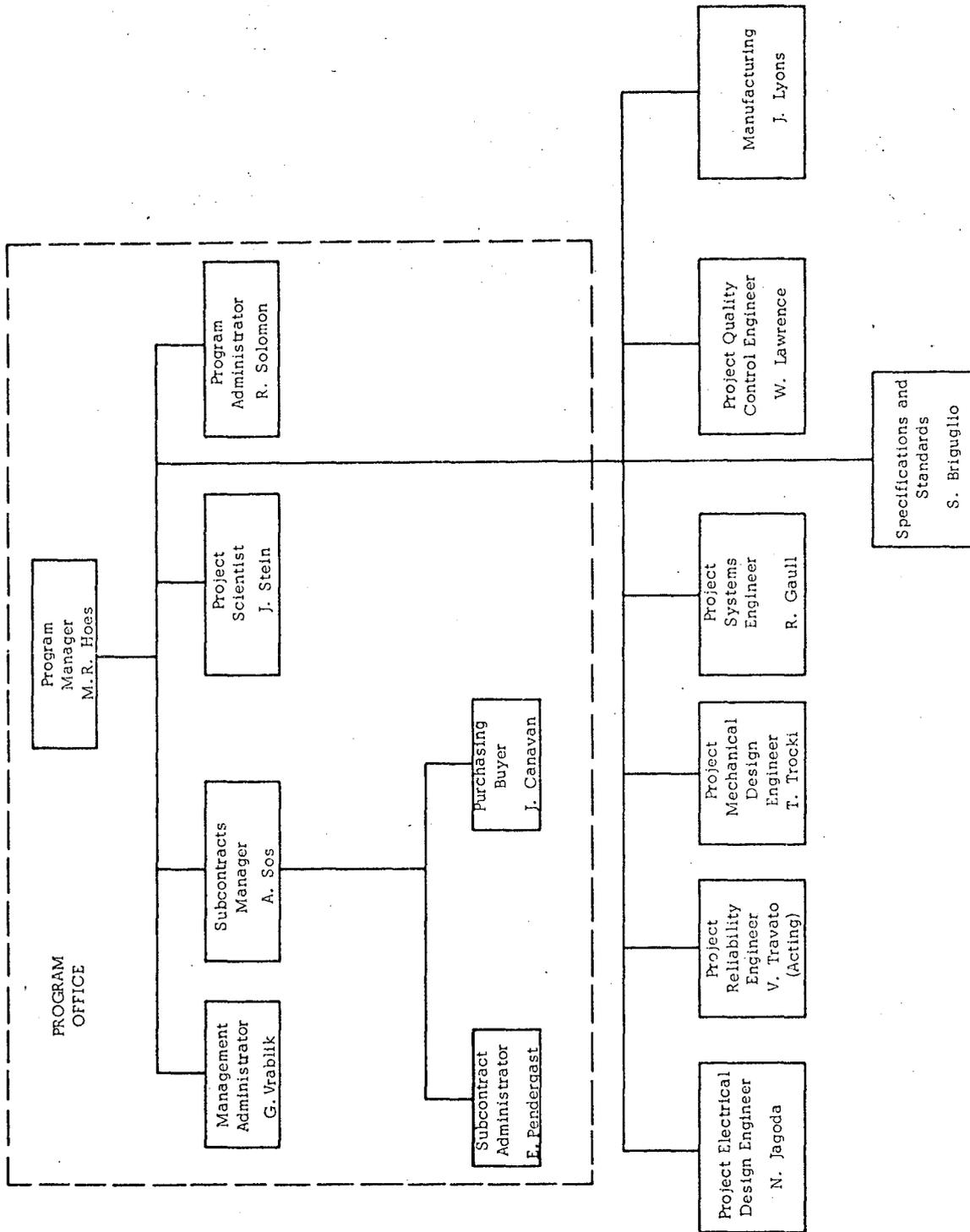


Figure 6-1. Apollo Program Office Organization Chart

Purchase requisitions for supplier items are subject, as a minimum to Program Office approval and are executed in accordance with American Science & Engineering purchasing procedures and applicable contractual requirements. A properly approved purchase requisition provides the Purchasing Department the authority to commit the company to a legal purchase order.

c. Management Controls

During the subcontract negotiation period, prior to the issuance of a purchase order, a satisfactory delivery schedule is established in accordance with the program needs. Milestones are defined for documentation and/or hardware deliveries in accordance with the contract requirements.

Upon execution of the purchase order week-by-week monitoring of that schedule is maintained so that any slippages become immediately apparent early in the procurement cycle.

Review and approval of all major purchase requisition change orders are conducted by the Program Manager/ Subcontracts Manager.

Weekly reviews are conducted by the Program Manager and Subcontracts Manager of each subcontractor milestone and status, to cover every critical aspect of each schedule.

Continuous telephone contact and liaison is maintained with each subcontractor to maintain a management awareness of day-to-day problems as they occur. When significant problems do occur, AS&E support may be provided and/or a resident AS&E representative may be assigned to provide the necessary assistance or surveillance to assure minimal impact to deliveries and requirements.

Periodic reviews are conducted with each subcontractor in the form of either status reviews or design reviews. At these reviews, the technical and delivery schedule status is determined against the program requirements to evaluate any real or potential impacts.

d. Change Directions

All change directions in their final form is executed as a change order to the purchase order.

Technical changes are accomplished via Engineering Change Orders (ECO's) or Specification Change Notices (SCN's) which are then incorporated into a new baseline via the purchase order change order.

Immediate technical or contractual change directives can be implemental as an on-the-spot authorization via the American Science & Engineering Change Directive by the Subcontracts Manager and the delegated Contracts Administrator up to a value of \$2,500. A sample of this Change Directive Form is shown in Figure 6-2.

No cost technical Change Directives require only the Subcontractors Manager approval.

Change Directions exceeding \$2,500 must be approved via the purchase requisition form and be approved in accordance with the approval procedure covered in paragraph 6.1.5a "Subcontracts Procedure".

e. Subcontract Status

Subcontractor status is maintained and updated periodically on milestone charts. A typical milestone is shown in Figure 6-3. Subcontractor status is determined by showing the:

- (a) Date of purchase order
- (b) Delivery dates
- (c) Required need dates
- (d) Actual deliveries from receiving records
- (e) Documentation milestone and approval date requirements (as applicable)

6.2 Major Sub-Contracts

6.2.1 Proportional Counters

Contract NAS9-9983  
Purchase Order # 57730  
Vendor: LND, Inc., Oceanside, L. I., N. Y.

	<u>Quantity</u>	<u>Price</u>
Original	32 pcs.	\$67,646.
No. Change Orders	4	
Final	32 pcs.	\$68,445.
Net Change	+ 1.2%	

The final cost falls well within the bounds contained in the philosophy of a CPFF contract.

AMERICAN SCIENCE & ENGINEERING, INC. CHANGE DIRECTIVE		2. CD NUMBER:	
1. TO:		ITEM:	
		3. DATE:	
4. PURCHASE ORDER:		5. EFFECTIVITY:	
6. SUBJECT:			
7. REFERENCES:		8. ENCLOSURES:	

9. You are hereby directed to proceed immediately with the following:

This direction is consistent with the general scope of work set forth in this Purchase Order and does not constitute new assignment of work or a change to the expressed terms, conditions or specifications, or delivery schedule incorporated into the Purchase Order.

Add additional CD sheets to expand upon item 9 as necessary.

10. TECHNICAL:	DATE:	11. CONTRACTS:	DATE:
12. SUBCONTRACTOR CONCURRENCE:	DATE:	13. Sheet _____ of _____	

Figure 6-2. Change Directive Form



### 6.2.2 Low Voltage Power Supply

Contract NAS9-9983

Purchase Order # 60978

Vendor: Time-Zero Corp., Torrance, Cal.

	<u>Quantity</u>	<u>Price</u>
Original	10 pcs.	\$152,456.
No. Change Orders	6	
Final	10 pcs.	\$209,008.
Net Change		+37.1%

Major reasons for increase in final cost.

- a) Design Deficiency in  $\pm$  6.75 volt regulator.
- b) Addition of management controls including full-time Program Manager (Vendor's).
- c) Addition of AS&E representative to vendor program staff.
- d) Addition of Incentive Payments to ensure delivery in accordance with revised schedule.
- e) Addition of "Quick-Fix" on prototype supply's only (at direction of MSC).

### 6.2.3 High Voltage Power Supply

Contract: NAS9-9983

Purchase Order: #58474

Vendor: Matrix Research and Development Corp.

	<u>Quantity</u>	<u>Price</u>
Original	14 pcs.	\$112,280.
No. Change Orders	3	
Final	14 pcs.	\$127,425.
Net Change		+ 13.5%

Major reasons for increase in Final Cost.

- a) Dual procurement of components to ensure meeting schedule.
- b) Addition of requirement for DC stress analysis.
- c) Change specification of output wire.
- d) Increase on unit price due to addition of revised specification.

#### 6. 2. 4 Ground Support Equipment (GSE)

Contract NAS9-9983

Purchase Order: #58629

Vendor: Gordon Engineering, Wakefield, MA.

	<u>Quantity</u>	<u>Price</u>
Original	4	\$133, 074.
No. Change Orders	3	
Final	4	\$136, 173.
Net Change		+2. 3%

The Final Cost falls well within the bounds contained in the philosophy of a CPFF contract.

#### 6. 2. 5 GSE Input-Output Unit (I. O. U)

Contract: NAS9-9983

Purchase Order: # 60803

Vendor: Compu-Systems Co. , Wakefield, MA

	<u>Quantity</u>	<u>Price</u>
Original	4	\$73, 300.
No. Change Orders	3	
Final	4	\$81, 100.
Net Change		+ 10. 6%

Major reasons for increase in Final Cost.

- a) Addition of ability to transfer data from one set of GSE to another.
- b) Addition of procurement specification for Input-Output unit for Bench Test Equipment.

#### 6. 2. 6 Charge Sensitive Preamplifier

Contract NAS9-9982

Purchase Order # 59019

Vendor: Washington Technological Associates, Rockville, Md.

	<u>Quantity</u>	<u>Price</u>
Original	65 pcs.	\$79, 990.
No. Change Orders	5	
Final	65 pcs.	\$107, 221.
Net Change		+34. 0%

Major reasons for increase in final cost:

- a) Addition of procurement specification S132-112.
- b) Incorporation of drawing SK132-113, Rev. D
- c) Increase in unit cost. As result of a) and b).
- d) Addition of procurement specification S132-112, Rev. D.
- e) Addition of AS&E ECO #1358.
- f) Addition of Parts Program.
- g) Addition of AS&E ECO # 5805
- h) Incorporate two SCN's
- i) Change in unit prices with change in quality levels.

6.2.7 A-D Converters

Contract: NAS9-9982

Purchase Order # 58924

Vendor: Space and Tactical Systems Corp., Burlington, MA

	<u>Quantity</u>	<u>Price</u>
Original	6 pcs.	\$109,445.
No. Change Orders	6	
Final	6 pcs.	\$116,195.
Net Change	+ 6.2%	

Major reason for increase in Final Cost.

- a) Addition of AS&E ECO #5802 (Burn-in requirement)

6.2.8 Alpha Detectors

Contract: NAS9-9982

Purchase Order # 59551

Vendor: Ortec, Inc. Oak Ridge, Tenn.

	<u>Quantity</u>	<u>Price</u>
Original	90 pcs.	\$54,000.
No. Change Orders	3	
Final	75 pcs.	\$50,069.
Net Change	-7.3%	

Major reason for decrease in Final Cost.

- a) Reduction in quantity ordered.

#### 6.2.9 Conclusions

In total the major subcontracts shown in this section had a net final cost change of + 14.5%. While this is somewhat higher than one would normally expect, we can attribute this mostly to problem areas encountered with the Low-Voltage Power Supplies (6.2.2) and Charge Sensitive Preamplifiers (6.2.6). Indeed, one can show that by eliminating 6.2.2 and 6.2.6, the net increase in final cost was only + 5.4%.

One can conclude from the above that for the most part, the subcontracts program at AS&E was reasonably well managed and effective in meeting the ultimate launch dates of Apollo 15 and 16.

## 7.0 FIELD OPERATIONS AND SUSTAINING EFFORT

### 7.1 Field Operations, Contractual Summary

Table VII-1 shows an historical summary of the activities initiated that resulted in the contract change notice #13 to NAS9-9982 and NAS9-9983 for test and launch operations at Kennedy Spacecraft Center, Florida.

Table VII-2 shows a line summary for the sustaining engineering effort at the contractors facility directed via CCN #23 to NAS9-9982 and NAS9-9983.

TEST AND LAUNCH OPERATIONS AT KSC

HISTORICAL SUMMARY

Proposal  
Level

<u>Date</u>	<u>No.</u>	<u>M/P</u>	<u>\$</u>	<u>Action Taken / Comments</u>
8 Sep. 70				Meeting at KSC to define level of support required to support test and launch operations (SOW 8 Aug. 70)
29 Oct. 70	ECP #11	9.0	\$753K	Submitted ECP to NASA/MSC
18 Nov. 70				Meeting at NASA/MSC. SOW held intact, cost reduction was requested.
30 Nov. 70	ECP #11A	6.5	\$509K	Submitted revised ECP to NASA/MSC.
11 Dec. 70				NASA/MSC fact-finding session held at AS&E. NASA/MSC requested revision to ECP #11A to reduce cost and manpower.
16 Dec. 70	ECP #11B	4.1	\$303K	Submitted revised ECP to NASA/MSC.
14 Jan. 71				ECP #11B approved as CCN #13 to NAS9-9982 and NAS9-9983.
2 Jun 71	ASE-2714			Submitted contract change proposal (ASE-2714) for combined field support and sustaining engineering.
3 Sep. 71				NASA/MSC requested separate proposals for field support and sustaining engineering be submitted by contract.
22 Nov. 71	ASE-2847	3.5	\$251K	Submitted contract change proposal for test and launch operations at KSC, Florida, for period through 30 April 1972.

TABLE VII-1

SUSTAINING ENGINEERING EFFORT AT AS&E

HISTORICAL SUMMARY

Proposal  
Level

<u>Date</u>	<u>No.</u>	<u>M/P</u>	<u>\$</u>	<u>Action Taken / Comments</u>
18 Nov. 70				Sustaining engineering was brought up at MSC by AS&E AS&E was told it would be discussed at a later date.
16 Dec. 70	ECP #13	6.8	\$408K	Submitted ECP to NASA/MSC for approval
14 Jan. 71				AS&E informed verbally that ECP #13 disapproved
17 Mar. 71				Program review at AS&E during which level of effort was agreed to.
16 Apr. 71	ECP #13A	4.4	\$285K	Submitted ECP in accordance with agreements of 17 Mar. 71.
29 Apr. 71				AS&E requested to defend ECP #13A at NASA/MSC.
4 May 71				NASA/MSC requested revision to ECP #13A to incorporate levels agreed to at MSC for period through 30 Aug. 71.
5 May 71	ECP #13B	4.9	\$102K	ECP submitted by telecon. Formal submission was to follow
17 May 71				CCN #23 to contracts NAS9-9982 and NAS9-9983 received ECP #13B was disapproved.
26 May 71	ECP #23	5.5	\$213K	Submitted ECP for sustaining effort through 15 April 72
2 Jun 71	ASE-2714			Submitted CCP (ASE-2714) (see table 7. 1).
3 Sep. 71				CCN #23 (Amend. #1) to NAS9-9982 and NAS9-9983 for sustaining eng. through 30 Apr. 72 was received. ECP #23 was disapproved.
3 Sep. 71				NASA/MSC requested submission of separate proposals (see Table 7. 1)
22 Nov. 71	ASE-2848	6.5	\$389K	Submitted contract change proposal for sustaining engineering effort at contracts facility, for period through 30 Apr. 72.

TABLE VII-2

## 7.2 Field Operations, Historical Summary

The following material is a chronological summary of significant accomplishments as well as problems experienced by the field team at KSC and covers the period from 19 January 1971 through the launch of the first Alpha/X-Ray Spectrometer experiment.

### 7.2.1 Field Report for Period 19 January Through 17 February 1971

- a. Organized the AS&E office at KSC.
- b. Performed NASA and North American Incoming Inspection on the Bench Test Equipment (BTE).
- c. Performed the BTE Acceptance Test.
- d. Performed Incoming Inspection on Flight Unit No. 1.
- e. Performed partial Pre-Installation Test (PIT) on Flight No. 1.
- f. Crated and shipped Flight No. 1 to AS&E, Cambridge.
- g. Performed Incoming Inspection of Flight Unit No. 2.
- h. Performed PIT on Flight No. 2.
- i. Installed Flight No. 2 in Simulator.
- j. Powered up X-Ray and Alpha Spectrometers.
- k. Tested QLDS System.

### PROBLEM AREAS

1. The following Discrepancy Reports were generated during the Receiving Inspection and PIT Testing of Flight Unit No. 1, S/N 7498.
  - a) DR AS-ASE-7498-0001 - The Certificate of Flight Worthiness was not signed off by MSC.  
  
This certificate will be signed off at the completion of Flight Readiness Review.
  - b) DR AS-ASE-7498-0002 - The Teflon Bushing in the Test Inject Connector of Alpha Detector No. 2 was damaged.

This connector will be replaced at AS&E during the Retrofit of the Alpha Detectors.

- c) IDR AS-ASE-7498-002 - Erratic computer printout of Table IA during the PIT Test. Problem was caused when the program was bombed by a glitch in the input power. The program was reloaded. This resolved the Problem.
2. The following Discrepancy Reports were generated during Receiving Inspection and PIT Testing of Flight Unit No. 2, S/N 7499.
- a) DR AS-ASE-7499-002 - The cable connector on the Solar Monitor was not identified. Identification was made by referring to Fig. 2, ASE Drawing 132-504, in the O.M. & H. Procedure, P132-145.
  - b) DR AS-ASE-7499-003 - The counts on Alpha Detectors No. 3 and 8 were too high. This condition required a waiver from MSC.
  - c) DR AS-ASE-7499-001 - Paint on SMA and SPA cracked and discolored. Condition of paint will not degrade its thermal characteristics, will fly instrument as is.
3. KSC had not been directed officially by MSC to curtail the use of solvents.
4. The QLDS has not been checked out sufficiently to verify the validity of the System or Program.

#### 7.2.2 Field Report for Period 18 February through 17 March 1971

During this reporting period the following major activities were accomplished: completion of the PIT test on Flight Unit No. 2, installation of the SPA and SMA in the spacecraft, performance

of a special spectrometer test (TPS 028) to check out QLDS data processing, performance of the Combined Systems Test (K-0070), and removal of the SPA and SMA from the spacecraft.

Numerous difficulties were encountered with QLDS processing of spectrometer data, during both TPS 028 and K-0070. The major problems were corrected but others are still open. A detailed listing of these is contained in the Combined Systems Test Report dated 16 March 1971. Only minimal hardware problems were encountered, the significant ones being the 100 mv noise spikes on the Alpha LVPS Temp. Mon. and the Alpha/PCM Sampling System phase difference. These are likewise described in detail in the CST Test report.

#### PROBLEM AREAS

Two problems were encountered. One concerns the Solar Monitor and the other the Spectrometer covers. The Solar Monitor ground strap Part No. is not specified in the Installation Procedure and there is no mounting hole in the spacecraft to attach the strap. In addition, a cutout in a bracket in front of the Solar Monitor must be modified to align with the front of the Solar Monitor. The Spectrometer covers are a multiple problem. First, the covers are made of Lucite which is not an acceptable material for use in the spacecraft; an acceptable alternative is Aclan. Second, the thin covers protrude above the Spectrometer and interfere with operation of the Mass and Gamma Spectrometers. Third, the method of attaching the covers to the Spectrometer is unsuitable for use in the spacecraft. The Alpha Detector Assembly Cover, in particular, requires removing structural hardware for mounting. To attach or remove these in the spacecraft requires tethering of all hardware and tools. Finally, the purge bag used to protect

the Alpha detectors covers the entire front of the Spectrometer and, hence, may not be useable after the SIM bay door is installed due to the restricted access space.

Another problem is the relative humidity in the experiment lab. To prevent damage to the Alpha Detectors, the relative humidity must be maintained below 60%. However, this has not been done consistently over the past two months: Typically, the humidity level is 58% with excursions up to 64%. NASA's response to our complaints has been that the environmental control system supplying the lab is not capable of doing any better.

### 7.2.3 Summary, QLDS Status for Alpha/X-ray Experiment as of 3 March 1971

A special test (TPS 028) was run on 25 February 1971 to operate the Alpha and X-Ray Experiments for QLDS Checkout. Both experiments operated in the normal flight mode for approximately thirty (30) minutes during which time the 64 K bit telemetry data was recorded on magnetic tape in the QLDS station. The data was also decommutated and processed by the QLDS computer in real time. During the first seven (7) minutes of the test, the real time processing was unsuccessful since the operator attempted to process Alpha and X-Ray data simultaneously, which is an invalid mode of operation for the QLDS computer. The operator then selected Alpha real time data processing for twenty (20) minutes, followed by X-Ray for the remaining three (3) minutes. This effort was successful, producing both the digital data and a short burst of analog data. Of course, the X-Ray data did not represent sufficient test time to allow proper evaluation.

On 26 February 1971, the tape was played back and both the Alpha and X-Ray digital data were reduced for the first twenty (20) minutes of the test. These records were then evaluated in detail along with

the previous records. The data agreed very well with that obtained during the PIT test and all results indicated that the experiments and the data system operated properly. However, a number of discrepancies were noted in the QLDS processing of the data, a list of which is shown below.

A meeting was then held on 2 March 1971 with NR and NASA QLDS representatives to review the results. Each discrepancy was discussed in detail and the required corrective actions were noted. Unfortunately, a commitment could not be obtained as to when the required program correction would be made. Informally, it was stated that no corrections could be made before the Combined Systems Test K-0070 due to begin on 9 March 1971. This was totally unacceptable since at least one of the errors (See X-Ray Item 1 on the next page) resulted in an irretrievable loss of data required to evaluate experiment performance. The remaining errors can be tolerated, although considerable effort will be required to perform calculations manually, etc.

Thus, a complaint was lodged with NASA, resulting in a promise that at least the one mandatory item (X-Ray Item 1) will be corrected before K-0070.

#### QLDS PROCESSING DISCREPANCIES

##### ALPHA

1. The histogram scaling technique uses 100 x's to represent the maximum count. However, channels with fewer than 1/100 of the maximum count have an x in them. Further explanation is needed of the technique being used.
2. When two or more PHA channels have the same number of maximum counts, the peak channel is calculated on the lower energy peak rather than the higher energy one.

3. The formula being used to compute Peak Height is not correct.

IS: 
$$PH = N_i + 1/2 (N_{i-1} - N_{i+1})$$

SHOULD BE: 
$$PH = N_i + 1/2 \cdot N_{i-1} - N_{i+1}$$

4. The Peak Width calculated for det. 1 is -24.39 channels which is not correct. Manual computation using the formulae in the SRD produced a value of 4.93 channels. The calculations for the other nine detectors produced correct results.
5. Measurement SL1065 Alpha Particle Count on the analog records is not correct. It indicates that counts were obtained in essentially all of the 256 channels, whereas, they were all confined to the first 50 channels in the PHA printout.
6. There are numerous glitches on the Alpha LVPS Temp. analog record. These consist of short duration temperature variations of  $\pm 3^\circ\text{C}$ . about the nominal value.

#### X-RAY

1. The PHA data in the Background and Calibrate tables is not correct for Detectors 2 and 3 (and presumably 4 as well, although no data was obtained for Det. 4 since the SMA was not installed). It appears that when the Cal & Gain flags are set, that the Det. 2, 3, and 4 data is being steered to the Background table instead of to the Calibrate table..
2. When the peak occurs in Channel 1 or Channel 8, the calculations for Peak Channel, Resolution, etc. are not performed. This is not correct. The program should ignore the data in Channels 7 and 8 when looking for the peak channel, and always perform the calculations on whatever peak is found in the first six channels.

3. The program requires that three (3) separate data accumulation runs be made to obtain computations for Peak Channel, Resolution, etc., and it then provides Spectral Range information as well. It is necessary to be able to obtain Peak Channel and Resolution information for just a single data run.

4. The formula for computing Resolution in percentage is incorrect, in that it applies only to peaks obtained from a Magnesium source. The correct formula is:  $RP = \frac{100 (RK)}{E}$  where E is energy of source in KEV for

Magnesium E = 1.25

Aluminum E = 1.49

Silicon E = 1.74

5. The formula for Gamma Ray Rejection is incorrect:

IS:  $G = 1 - C/D \pm [ 1/\sqrt{c} + 1/\sqrt{a} ]$

SHOULD BE:  $G = 1 - C/D \pm C/D [ 1/\sqrt{c} + 1/\sqrt{a} ]$

6. The Histogram plots the PHA SUM, PSD, and PHA and PSD counts in addition to the Channel 1 - 8 counts. This results in a scale factor that distorts the PHA 1 - 8 data and makes the Histogram totally unuseable. Only the PHA 1 - 8 data should be plotted.

7. The SRP indicates that only the two most significant bits of that status words (Words 77 - 80) are being used. All four significant bits must be used for the analog record displays so that the actual Cal Rod status can be determined.

7.2.4 Summary, Field Report for Period 18 March through 24 March 1971

Major Activities:

- a) Pre-ship test of the Flight 2 Instrument.
- b) Return of the Flight 2 Instrument to Cambridge for modification.
- c) Post test review of 0070 Combined Systems test data.

Major Problems:

- a) Apparent noise pickup within the X-Ray experiment which occurred during Combined Systems portion of K-0070 Test.
- b) Present Spacecraft scheduling requires experiment available for installation on April 20. Present Flight 1 delivery date of April 15 does not permit the five (5) working days required for Receiving inspection, generation of front end gain verification tapes and PIT testing.

Open Items:

- a) Open DR's included with the shipped Flight 2 Data Package. (DR's AS-ASE-7499-0006, 7, 8, & 9).
- b) IDR 055 - Combined Systems noise pickup problem.
- c) Effects that Structural X-Raying of the Spacecraft may have in the instrument.

7.2.5 Summary, Field Report for Period 25 March through 7 April 1971

Major Activities:

- a) Investigation of apparent noise pickup within the X-Ray experiment which occurred during Combined Systems portion of K-0070 Test and during TPS 028 testing (DR 262).

Major Problems:

- a) Isolation of the noise source which affected the X-Ray data during Combined Systems portion of K-0070 test and during TPS 028 (DR 262).
- b) Present Spacecraft scheduling requires experiment available for installation on April 20. Present Flight 1

delivery date of April 15 does not permit the five (5) working days required for Receiving inspection, generation of front end gain verification tapes and PIT testing.

Open Items:

- a) Open DR's included with the shipped Flight 2 Data Package (DR's AS-ASE-7499-0006, 7, 8 & 9).
- b) DR 262 (was IDR 055) - Combined Systems noise pickup problem.
- c) Effects that Structural X-Raying of the Spacecraft may have on the instrument.
- d) Details for the handling and operation of the latest Alpha purging system and X-Ray Helium fixture.
- e) Details for the installation and removal of the non-flight instrument covers.

7.2.6 Summary, Field Report for Period 8 April through 12 May 1971

Major Activities:

- a) Received and inspected Flight Unit I Mod. A.
- b) Removed sources from alpha detectors 1, 4, 5, 9 & 10 per Directive MSC CCBBD 0J00698.
- c) Performed PIT.
- d) Installed new covers per AS&E ECO 6652.
- e) Completed AS&E ECO 6763 (shock mount interference modification).
- f) Installed shock mounts on spectrometer processor assy.
- g) Installed experiment in spacecraft.
- h) Completed TPS 055 (K-0070 Rerun).
- i) Performed portion of DR 262 troubleshooting plan.
- j) Completed High Gain Antenna (HGA) Test, K-8241.
- k) Troubleshoot phantom pulse at channel 106 of Det. 5 observed during TPS 055 (TPS 055 IDR 014).
- l) Supplies interface information for alpha purge from facility GN<sub>2</sub>.

Major Problems:

- a) Open Discrepancy Reports (DR's) and/or Interim Discrepancy Reports (IDR's):
  1. S/C 112 DR 262 (X-Ray noise pickup) - yet to test in one configuration.
  2. S/C 112 DR 380 (Det. 7 resolution 5.5%) - authorization for detector replacement in route from KSC. Spare modules now at KSC.
  3. S/C 112 DR 381 (SMA connector ID) - waiting copy of ECO from Cambridge.
  4. S/C 112 DR 408 (gaps in RCS plume door seal) - AS&E does not concur with NAR disposition to "use as is".
  5. DR 470 (formerly IDR 014) (Excess alpha background counts) - Under investigation to determine cause of phantom pulse and a waiver or other documentation indicating contamination on detectors other than detectors 3 & 8 is required. (During TPS 055, counts in all channels exceeded the 100 count maximum specified in the TCN).

7.2.7 Summary, Field Report for Period 13 May through 13 June 1971

Major Activities:

- a) Replaced Alpha Detector Amplifier Assembly #7 in Flight Unit 1 Mod A. (S/N 7462 replaced with S/N 7576) S/N 7462 returned to AS&E Cambridge for further testing and analysis.
- b) Received and inspected Flight Unit 11 Mod A.
- c) Performed Integrated Test (K-0005), both System Test and SIM Flight portions.
- d) Hooked up Alpha Purge to facility GN<sub>2</sub> system.
- e) Performed resolution measurement of Alpha Det. 7 with pulse generator.
- f) Wrote test procedure for Flight 11 A pre-integration testing.
- g) Closed out all outstanding DR's.
- h) Participated in FRR meeting activities.

Outstanding Problems:

- a) S/C 112 DR 408 - gaps in RCS Plume Door Seal. Although this DR has been closed officially, we are not yet satisfied that they have adequately demonstrated the elimination of the gap.
- b) Redesign of Alpha Purge Cover. The new purge cover has been received, but has not yet been fit checked. This cannot be done until the SIM Bay door is installed and this is being delayed by hardware interferences.

7.2.8 Summary, Field Report for Period 14 June through 13 July 1971

Major Activities:

- a) Performed Experiment tests to verify operation after lightning strikes on the MSS.
- b) Reworked the RCS Plume Door to eliminate interferences with SM-1.
- c) Verified more complete sealing of the RCS plume door against the Spectrometer gasket (Ref. S/C 112 DR 408).
- d) Fit tested the modified Alpha purge panel and verified the ability to install and remove the RCS plume door, purge panel and X-Ray Sensor panel through the opening in SM-1.
- e) Stopped NR from coating all exposed screws on the experiment with RTV 566.
- f) Performed K-0028 Flight Readiness Test.
- g) Reviewed S/C 113 test flow and Experiment test requirements with NR, NASA/KSC and NASA/MSC.
- h) Installed SM-1 for flight.
- i) Received IOU S 'N #4 and performed verification test on it.
- j) Performed post shipping verification test on Flight Unit II Mod. A.
- k) Performed K-0007 Countdown Demonstration Test.
- l) Stopped NR from using RTV 102 on the SM-28 door.

Outstanding Problems:

There are no outstanding problems. However, the following Flight II items remain open because there has not yet been time to perform the required work:

- a) DR-AS-ASE-7499-0011 - nut plate fell off the Experiment Protective cover (SK 132-3217).
- b) DR-GASE-683-004-0001 - cables shipped in with new IOU do not have part numbers on them.

7.2.9 Summary, Field Report for Period 14 July through 12 Aug. 1971

Major Activities:

- a) Established a workable sequence of flight closeout activities to minimize the risk of Alpha detector contamination by the RTV 102 used to seal the SIM Bay for flight.
- b) Generated the Front End Gain Verification tape for Flight II A.
- c) Troubleshoot and repaired the lab Input/Output Unit (IOU).
- d) Performed K-0007 Count Down Test.
- e) Supported launch of Apollo 15.
- f) Calibrated and revalidated the Bench Test Equipment (BTE).
- g) Generated shipping instructions for shipping the Flight I A shipping container to NR, Downey, California.

Outstanding Problems:

- a) Resolution of the Solar Monitor protection against humidity during move to the launch pad.
- b) Suspect high counts observed in X-Ray lower channels may result in a repeat of the noise problem encountered with this unit during K-0070 testing with the spacecraft 112.
- c) Differences between peak channels for Alpha Det. 7 when electronic stimulation is controlled manually verses when controlled by the computer.

7.2.10 Summary, Field Report for Period 13 August through 13 September 1971

Major Activities:

- a) Alpha Detector Amplifier Assembly No. 7 found defective. Replaced with on-hand spare assembly.
- b) Performed Flight II-A Pre-Installation Test (PIT).
- c) Spacecraft installation was postponed to troubleshoot X-Ray noise problem.
- d) Prepared and shipped the instrument to Cambridge for further troubleshooting of item c above.

Outstanding Problems:

- a) The instrument was returned to Cambridge for isolation of X-Ray noise problem with two open Discrepancy Reports (DR s). The DR s are as follows:
  1. DR-AS-ASE-7499-016 (Ref. Failure Report K-KD-0486) - X-ray noise problem.
  2. DR-AS-ASE-7499-017 - Bent pin on the string tied shorting plug for X-Ray Test Point (TP) 2.
- b) Accompanying the instrument to Cambridge, as a backup IOU, is IOU S/N 004 with the following two open DR s:
  1. DR-GASE-683-004-003 - IOU invalidated when A/D converter modules were removed to troubleshoot IOU S/N 003.  
  
Revalidation had not yet been performed at KSC prior to shipping.
  2. DR-GASE-683-004-004 (Ref. Failure Report K-KD-0487) - ADC Multiplexer card removed from the IOU S/N 004.  
  
This card was removed from this IOU to replace the failed card in IOU S/N 003. To expedite shipping, the card was not installed, but was shipped along with the IOU.

7.2.11 Summary, Field Report for Period 14 September through 8 October 1971

Major Activities

- a) Prepared all the necessary procedures in preparation for receiving the instrument at KSC on or about 26 October, including a procedure to reinstall the Alpha on-board sources previously removed at KSC.
- b) Purchased picture frames and hung pictures of the instrument about the office.
- c) Reviewed available Spacecraft 113 test procedure as follows:
  1. K-0070 (Abbreviated Combined Systems Test)- incorporated revised test philosophy which basically reduced the Alpha hand held sources test accumulations from 1 hour to 1/2 hour, and uses the Programmable Pulse Generator (PPG) to stimulate the Alpha experiment to verify the 8 Alpha Digital lines.
  2. The first cut of K-0005 (Integrated Test at the Pad) was written to reduce the overall experiment testing time. To reduce the AS&E test time the Alpha and X-Ray external source tests will be run on both experiments simultaneously rather than serially. The Quick Look Data Station (QLDS) claims they are programmed to handle data from both experiments simultaneously. The Alpha Normal Test will be run after the external test with at least a one hour wait period between tests to minimize the effects of the contaminated sources. The phantom peak produced by the sources will probably be masked since all on-board sources will be installed.
  3. K-3550 (Installation Procedure) was reviewed. A facility N<sub>2</sub> supply has now been provided in the Altitude chamber for purging the Alpha experiment.
- d) The hand held X-Ray sources S/N's 276, 277 & 278 were shipped to Cambridge to be used in the post modification acceptance test. These sources are not the spare sources but are the same ones used for testing at KSC. The spare sources are not mounted in handles. Since sources in handles were required at Cambridge the above were

shipped. It would have required too much time to generate all the paperwork to ship the spares with or in the handles.

- e) A 6-month periodic wipe test was performed on all the hand held sources including those shipped to Cambridge.
- f) R. Gaillardetz has spent the better part of this reporting period, at Cambridge, in support of the X-Ray noise troubleshooting effort.

7.2.12 Summary, Field Report for Period 9 October 1971  
Through 17 November 1971

Major Activities

- a) Received and inspected the Flight II B instrument at KSC.
- b) Completed the reinstallation of the five (5) Alpha on-board calibration sources which had been previously removed at KSC.
- c) Completed Pre-Installation Test (PIT) activity including special test to establish baseline data with the new modification.
- d) Completed the shock mount installation.
- e) Completed the installation on the spacecraft.
- f) Received and inspected the Alpha Detector Amplifier Assembly S/N 7367.
- g) Completed the Alpha Detector Amplifier Assembly No. 1 replacement.
- h) Completed the spacecraft Combined Systems Test K-0070
- i) Shipped Alpha Detector Amplifier Assembly S/N 7253, to Cambridge for repair.

Outstanding Problems

- a) Programmable Pulse Generator (PPG) S/N 130 in KSC Calibration Lab awaiting new parts from PPG vendor.
- b) IDR's & DR's
  - S/C 113 SIM 066 - Incorrect alignment, of the RCS plume shield door, with the instrument.
  - S/C 113 SIM 075 - Open wire in the spacecraft cabling, which carries the X-Ray Lunar Detector Temperature housekeeping monitor.
  - AS-ASE-SPARES-0004 - Alpha Detector Amplifier Assembly S/N 7253 returned to Cambridge to repair loose signal inject connector.

7.2.13 Summary, Field Report for Period 18 November  
Through 6 December 1971

Major Activities

- a) Completed the retest to verify the spacecraft/experiment interface connections to close out DR 113 SIM 0075.
- b) Completed the High Gain Antenna (HGA)/Experiments Compatibility Test, K-8241.
- c) Completed the alignment and fit of the RCS plume shield door to close out DR 113 SIM 0066.

Outstanding Problems

- a) Programmable Pulse Generator (PPG) S/N 130 in KSC Calibration Lab awaiting parts from PPG vendor. Estimated completion - 24 December.
- b) DR AS-ASE-SPARES-0004-Alpha Detector Amplifier Assembly S/N 7253 returned to Cambridge to repair loose signal inject connector.
- c) Receipt of the new X-Ray calibration sources required to support K-0005 testing.

7.2.14 Summary, Field Report for Period 7 December 1971  
Through 12 January 1972

Major Activities

- a) Apollo 16 moved to Launch Complex 39A.
- b) Completed receiving inspection of the spare X-Ray hand held sources.
- c) Completed receiving inspection of the Alpha Detector Amplifier Assembly S/N 7253, closing DR AS-ASE-SPARES-0004.
- d) Completed K-0005 System Test at the Pad.
- e) Troubleshooting Interim Discrepancy Report (IDR) 012 initiated during K-0005 testing.

Outstanding Problems

- a) IDR K-0005 - 012: Out-of-spec. condition of the X-Ray DET 2 and 3 Spectral Range during K-0005 System Testing.
- b) Programmable Pulse Generator still in KSC Calibration Lab for repair. Estimated completion - 10 January.
- c) Source transfer form No. 1625, required from Cambridge for completion of the Alpha Detector Amplifier Assembly paperwork.

7.2.15 Summary, Field Report for Period 12 January 1972  
Through 3 February 1972

Major Activities

- a) Completed K-0005 testing.
- b) Completed troubleshooting activity against IDR K-0005-12, the out-of-spec. condition of the X-Ray Det. 2 and 3 Spectral Range.
- c) Transferred IDR K-0005-12 from a discrepancy against the experiment to one against the new hand held X-Ray sources as DR-AS-ASE-SPARES-0005.
- d) Returned the old as well as the new X-Ray source, to Cambridge for spectrum analysis to close out DR-AS-ASE-SPARES-0005.
- e) The repaired Programmable Pulse Generator was finally returned from the KSC Cal Lab and installed in the Bench Test Equipment (BTE) to close out DR-AS-ASE-SPARES-0003 and Failure Report FIAR KKD-0498.
- f) Waivered recalibration of the BTE since there is no scheduled usage.
- g) Apollo 16 was returned to the VAB on 27 January and the CSM was returned to the High Bay in the MSO for repair of an RCS fuel tank, which ruptured during test at the Pad. This did not change the 16 April 1972 launch date.

Outstanding Problems

- a) Close out of DR-AS-ASE-SPARES-0005 against the x-ray sources is pending the completion of the source spectrum analysis.
- b) What to do with all the equipment at KSC upon completion of lunar activities at KSC after launch of Apollo 16

7.2.16 Summary, Field Report for Period 4 February 1972  
Through 2 March 1972

Major Activities

- a) Apollo 16 was returned to Pad 39A on 9 February. In spite of exposure to two (2) days of rain during the move, the 60% maximum relative humidity requirement was not exceeded.
- b) Completed K-0005 Retest after the move to the Pad.

- c) Closed out IDR-10 which was initiated during K-0005 Retest due to a low total PHA count in Alpha Detector 7. The low count was due to natural decay of the on-board source.
- d) Received and inspected the X-Ray hand held sources which were returned to KSC after spectrum analysis.
- e) Closed DR-AS-ASE-SPARES-0005 against the new sources after the spectrum analysis verified the higher Gamma Ray to X-Ray ratio of the new sources.
- f) Completed the Flight Readiness Review.
- g) Completed the Flight Readiness Test (K-0028).

Outstanding Problem

Need from Cambridge, a completed form MSC 1625, which correctly identifies the on-board source installed in Alpha Detector Amplifier Assembly S/N 7253.

7.2.17 Summary, Field Report for Period 3 March 1972 Through 3 April 1972

Major Activities

- a) Completed K-0007 Countdown Demonstration Test (CDDT).
- b) Received authorization from MSC to return BTE and other support equipment to Cambridge upon completion of KSC field activities.
- c) Started shipping procedures and packing.
- d) The Launch Umbilical Tower at the pad was struck by lightning on 31 March.

Outstanding Problems

None.

7.2.18 Summary, Field Report for Period 4 April Through 3 May 1972

Major Activities

- a) Completed SIM Bay close out, including removal of experiment protective covers, installation of plume door and SIM doors, and final Alpha and X-Ray tests
- b) Launched Apollo 16, as scheduled, on 16 April 1972.
- c) Provided mission support at MSC in Houston.

- d) Completed packing and shipping preparations for all equipment and files.
- e) Closed out the KSC Field Office.

#### Outstanding Problems

None.

#### Future Activities

None. Field activities at KSC have been terminated.

#### 7.2.19 Summary, Field Report for Period 4 May 1972 Through 31 May 1972

#### Major Activities

- a) Phase down of hardware phase of experiment.
- b) Returned all equipment from KSC to AS&E, checked out same, and placed in bonded stores.
- c) Prepared final report revision for publication.

## 8.0 CONCLUSIONS

The Apollo Lunar Alpha and X-Ray Spectrometers Program was initially devised as a rapid design, manufacture, and test program to provide experimental payloads for Apollos XIV, XV, and XVI with one spare. The rapid turn around (6 months from date of contract initiation to delivery of first flight article, and 18 months to delivery of final flight article) necessitated the parallel manufacture and test of the prototype, qualification model, and the first two flight articles.

The lack of time in which to debug the initial circuit design and to incorporate those changes in later models required an inordinate amount of ECP's, ECO's, and rework, which was not only time consuming, but also very costly. This extremely short time scale also necessitated taking short cuts in procurement, namely, double procurement to ensure timely delivery, release of sub-contracts with less than perfect procurement specifications, and other such measures that add considerably to the cost of a program.

What with all the technical and financial problems associated with the ALOS Program and AS&E, it is still worthwhile to note that the AS&E spectrometers were the first major experiments delivered for Apollos XV and XVI, the first experiments to be qualified for flight, and the first to be certified flight-worthy. Their performance on Apollos XV and XVI was excellent, and in terms of the returned scientific data, will contribute greatly to man's understanding of his nearest neighbor.

The following document is a sample of the type of information we have already learned from the Apollo XV flight and expect from the Apollo XVI flight.

(Appendix A) "Observation of Lunar Radon Emanation with the Apollo 15 Alpha Particle Spectrometer" - P. Gorenstein and P. Bjorkholm, January 1972.

APPENDIX A

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OBSERVATION OF LUNAR RADON EMANATION\*  
WITH THE APOLLO 15 ALPHA PARTICLE SPECTROMETER

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and

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ABSTRACT

The alpha particle spectrometer, a component of the orbital Sim Bay group of "geochemistry" experiments on Apollo 15, was designed to detect alpha particles emitted during the decay of isotopes of radon gas and her daughter products. The purpose was to measure the gross activity of radon on the lunar surface and to find possible regions of increased local activity. Results are presented from a partial analysis of Apollo 15 data. For the Moon as a whole,  $^{220}\text{Rn}$  was not observed and the upper limit on its decay rate above the lunar surface is  $3.8 \times 10^{-4}$  disintegrations/cm<sup>2</sup>-sec.  $^{222}\text{Rn}$  was marginally observed, but until further analysis can be carried out, we report the result as an upper limit of  $10^{-3}$  disintegrations/cm<sup>2</sup>-sec. Possible variations of radon activity on the lunar surface are being investigated.  $^{210}\text{Po}$  (a daughter product of  $^{222}\text{Rn}$ ) has been detected in a broad region from west of Mare Crisium to the Van de Graaf-Orlov region. The observed count rate is  $(4.6 \pm 1.4) \times 10^{-3}$  disintegrations/cm<sup>2</sup>-sec. The observed level of  $^{210}\text{Po}$  activity is in excess of the amount that would be in equilibrium with  $^{222}\text{Rn}$  by about an order of magnitude. This implies that larger levels of radon emanation have occurred on the Moon within a time scale of  $10^1 - 10^2$  years.

## 1.0 INTRODUCTION

Analysis of returned lunar samples has revealed significant concentration of uranium and thorium in lunar surface material. Both elements are unstable against radioactive decay and are the first members of two distinct highly complex decay series which terminate in stable isotopes of lead. Unstable isotopes of radon gas are produced as intermediate products of these series. Uranium produces  $^{222}\text{Rn}$  and thorium produces  $^{220}\text{Rn}$ . Radon is a rather special component of the decay series because it is a noble gas. There is a possibility that the radon will diffuse above the lunar surface where it remains trapped in an exceedingly rare atmosphere by the Moon's gravity. As a result, the radioactive decay of the radon isotopes and their daughter products would have the effect of enhancing the radioactivity levels upon the surface of the Moon.

Radon emanation from the soil is a well-known terrestrial phenomenon. Various effects promote the diffusion of easily detectable activity levels of radon into the atmosphere. Across the surface of the Earth there exists gross differences in the amount of radon emanation that reflect local differences in concentrations of uranium and thorium and the ability of radon to diffuse through the soil. Generally speaking, there is a high degree of atmospheric radon activity where there is a high concentration of uranium and thorium. Volcanic activity and the evolution of volatiles from the ground is generally accompanied by radon emanation. Hence, a radon emanation map of the Earth would be exceedingly non-uniform.

It is not unreasonable to expect that analogous effects are taking place across the surface of the Moon. Significant concentrations of uranium and thorium, comparable to terrestrial values, are found. However, conditions on the Moon are quite different from the Earth. Some of the differences which may retard the diffusion of radon on the lunar surface are a lack of an atmosphere, lack of water vapor, and the grain size of the soil. Since

the alpha spectrometer can only detect radon and her daughter products at or above the lunar surface, any retardation of the emanation and diffusion of radon will reduce the observed signal.

It is extremely difficult to determine a priori how the very high vacuum conditions in the soil affects the diffusion of radon. Previous measurements of lunar radon activity (to be discussed below) lead us to conclude that it retards diffusion in general. However, it might be expected that the presence of crevices or fissures in local regions which increase the amount of exposed surface would enhance the quantity of radon evolved into the atmosphere. It is quite reasonable to expect that volcanic or thermal sources of ordinary volatiles such as water vapor or carbon dioxide should they exist on the Moon would also be sources of radon as they are on the Earth. The movement of these common gases through rocks and material that contain uranium and thorium would very likely sweep radon to the surface. Because the uncertainties in this process are so large it is not possible to make a quantitative estimate of the amount of radon reaching the surface.

An early estimate by Kraner, Schroeder, Davidson and Carpenter (1966) assumed terrestrial conditions for the diffusion coefficient and concentrations. When the actual concentrations of uranium and thorium are used their model predicts a rate of two disintegrations per sec  $\text{cm}^2$  for  $^{222}\text{Rn}$  and about  $10^{-2}$  disintegrations per sec per  $\text{cm}^2$  for  $^{220}\text{Rn}$ . Actual observations of alpha emission from the Moon have indicated that if the radon is present, the activity levels are considerably smaller than this. A measurement by Yeh and VanAllen (1969) from lunar orbiting Explorer 35 found no indication of alpha particle emission and set an upper limit that was about one-tenth of the value predicted by Kraner et al. (1966). Turkevich et al. (1970) reporting on background data obtained in the Surveyor 5, 6 and 7 alpha backscatter experiments cited evidence for a radioactive deposit at Mare

Tranquillitatis (Surveyor 5) with an intensity of  $0.09 \pm 0.03$  alpha disintegrations per sec per  $\text{cm}^2$ . Their instrument was deployed looking at and close to the lunar surface, well below the several kilometer scale height of any radon atmosphere. Thus, the Surveyor instrument was sensitive to only a small fraction of the total radon atmosphere. At the other two sites, Sinus Medii (Surveyor 6) and rim of Tycho (Surveyor 7), they report only upper limits to the alpha activity that are about a factor of two or three lower than Mare Tranquillitatis.

There are two other indirect measurements of alpha activity that look for the active deposit on returned samples that have been exposed to lunar radon. Lindstrom, Evans, Finkel, and Arnold (1971) looked for an excess of the radon daughter  $^{210}\text{Pb}$  in Apollo 11 samples. They fail to find an excess to within 3%, which implies that the effect of the active deposit is less than  $10^{-4}$  predicted by Kraner et al. This is the most pessimistic of all the experiments. However, there is a possibility that all or nearly all of the active deposit which resides entirely in the first micron of surface material could have been blown away by the action of the LM descent engine. A similar measurement was made by Economou and Turkevich (1971) upon the Surveyor 3 camera visor which was returned to Earth from Oceanus Procellarum by the Apollo 12 astronauts. They found no evidence for the deposit and can set an upper limit that is about six times smaller than the value reported by Turkevich et al. for Mare Tranquillitatis. Here again one must remember that the slightest amount of abrasion or erosion could remove most of the active deposit. The net result from these pre-Apollo orbital measurements is that the active deposit on the lunar surface is probably several hundred times smaller than terrestrial diffusion rates would predict.

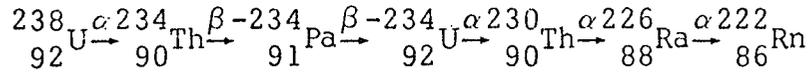
An interesting question concerns the degree to which radon remains localized. Any radon atoms reaching the lunar surface will move in ballistic trajectories. Emitted at thermal velocities of about 0.15 km/sec, at  $300^\circ\text{K}$ ,

they are decelerated by the gravitational pull of the Moon. Typically, they reach a maximum altitude of about 10 kilometers and fall back upon the surface. Essentially, no atoms have sufficient velocity to escape. It is evident that most of the shorter lived isotope  $^{220}\text{Rn}$  ( $T_{1/2} = 55$  sec) decays on its first ballistic trajectory. The alpha emission from  $^{220}\text{Rn}$  and its daughter is confined to a region with a radius of 10 kilometers around the point of emanation, thus preserving the localization to a very high degree. On the other hand,  $^{222}\text{Rn}$  ( $T_{1/2} = 3.8$  days) has sufficient time to migrate a considerable distance prior to decay. The largest uncertainty is the accommodation time or the elapsed time between the return to the surface of a freely falling radon atom and its reemission on a new trajectory. If we assume for an average  $^{222}\text{Rn}$  atom a thermal velocity ( $300^\circ\text{K}$ ) and an emission angle of  $45^\circ$ , it impacts about 5 Km from its point of emission and the process requires about 32 seconds. If the accommodation time is zero, then  $2 \times 10^4$  bounces are possible during one mean life of  $^{222}\text{Rn}$ . Hence, the displacement from the original point of emission is  $\sqrt{2 \times 10^4} \times 5$  km or 700 Km. For either non-zero accommodation time or lower temperatures, there will be a smaller spread of the activity. In any case some degree of localization may be preserved. Heyman and Yaniv (1971) have described a theoretical model for the displacement of  $\text{Rn}^{222}$  in which they predict a pile-up of  $^{222}\text{Rn}$  at the sunrise terminator of the Moon.

Detection of radon is, in the Apollo experiment, based on the fact that alpha particles are produced in its decay. Table I and II list the kinetic energies of the alpha particles that are emitted by the radon isotopes of the uranium and thorium series plus the energies of the alphas from their subsequent daughter products. Alpha particles from the decay of radon above the lunar surface will be seen at their full energy for there can be no significant slowing down in the lunar atmosphere. When the radon decay is such that an alpha particle is emitted upward a recoil nucleus with a kinetic energy of about one hundred kiloelectron volts is

deposited on the lunar surface. The distance in which the heavy recoil nucleus is brought to rest is very much smaller than the range of the alpha particles that will be emitted subsequently. Hence the active deposit is itself a source of monoenergetic alpha particles. On the other hand, no alpha particles will reach the surface from radon which decays at a depth exceeding the alpha particle range. Typically, this is about 10 microns. Thus, alphas which are emitted between 0 and 10 microns are degraded in energy. Hence, the intensity of monoenergetic alpha particle emission is highly dependent on the effectiveness of the diffusion process.

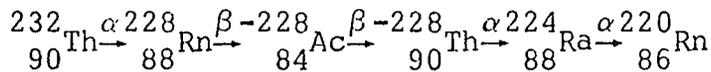
TABLE I



Isotopes	Half-Lives	$\alpha$ -Energies (MeV)	Relative Intensities
${}^{222}_{86}\text{Rn}$	3.823 days	5.490	100
${}^{218}_{84}\text{Po}$	3.05 min	6.002	50
${}^{214}_{82}\text{Pb}$	26.8 min	$\beta$ -	--
${}^{214}_{83}\text{Bi}$	19.7 min	$\beta$ -	--
${}^{214}_{84}\text{Po}$	$164 \times 10^{-6}$ sec	7.687	50
${}^{210}_{82}\text{Pb}$	21 y	$\beta$ -	--
${}^{210}_{83}\text{Bi}$	5.01 days	$\beta$ -	--
${}^{210}_{84}\text{Po}$	138.4 days	5.305	50
${}^{206}_{82}\text{Pb}$	Stable		

Uranium (Radium) series showing in detail the origins, half-lives energies and relative intensities of the main  $\alpha$ -groups starting with radon ( ${}^{222}\text{Rn}$ ). The relative intensities are normalized to 100 decays of  ${}^{222}\text{Rn}$  above the lunar surface.

TABLE II



Isotopes	Half-Lives	$\alpha$ -Energies (MeV)	Relative Intensities
${}^{220}_{86}\text{Rn}$	55 sec	6.287	14
${}^{216}_{84}\text{Po}$	0.158 sec	6.777	7
${}^{212}_{82}\text{Pb}$	10.64 hr.	$\beta$ -	--
${}^{212}_{83}\text{Bi}$	60.0	6.090 6.051	0.7 1.8
${}^{212}_{84}\text{Po}$	$.304 \times 10^{-6}$ sec	8.785	4.5
${}^{208}_{81}\text{Tl}$	3.10 min	$\beta$ -	--
${}^{208}_{82}\text{Pb}$	Stable	--	--

Thorium series showing in detail the origins, half-lives, energies, and relative intensities of the main  $\alpha$ -groups, starting with Thoron ( ${}^{220}\text{Rn}$ ). The relative intensities are normalized to 100 decays of  ${}^{222}\text{Rn}$  above the lunar surface and assuming at 7:1 ratio for the  ${}^{222}\text{Rn}/{}^{220}\text{Rn}$ , as reported by Turkevich et al. (1970).

## 2.0 EQUIPMENT

The spectrometer is designed to measure the energy of any incident alpha particles even in the presence of other energetic charged particles. The sensing elements are ten totally depleted silicon surface barrier detectors. They are each approximately 100 microns thick,  $3 \text{ cm}^2$  active area, have a  $90^\circ$  field of view, and operate at -50 volts bias. Additional gold, aluminum and nickel layers were used at the contacts to assure light tight performance. The thickness of the detectors was chosen so that any background protons (deuterons or tritons) would give an output pulse of less than that for a 5 MeV alpha particle while the output for alpha particles up to 12 MeV would be linearly proportional to energy. This precludes the necessity for discriminating against other particles in any other way.

The ten detector pre-amplifier outputs are merged in a single summing amplifier and processed by a single analog to digital converter (ADC). While the use of one ADC minimizes the complexity of the hardware, it also means that the noise from all ten preamps is summed, resulting in a resolution degradation of about a factor of three. To circumvent this, each preamplifier has a bias offset of approximately 350 keV. This effectively removes the noise and allows the use of a single ADC without resolution degradation.

The ADC converts the energy pulse into a 9-bit digital signal. If the most significant bit is a 1, the ADC is disabled and the digital signal held until the next telemetry readout (every 100 milliseconds). If the most significant bit is zero, the ADC is reset and the next pulse is processed. This allows the instrument to digitize to a 9-bit accuracy and only transmit 8 bits.

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This means that only the upper half of the digitized energy range is telemetered. Physically this is reasonable since the alpha energies of interest range from 5.3 to 8.8 MeV and it also prevents the usage of telemetry time by any low energy background. The actual telemetered energy range of the instrument was from 4.7 to 9.1 MeV. Parallel circuitry generates an analog signal from 0.25 to 4.75 volts, in steps of 0.5 volts, which identifies the detector which originated any given pulse.

Since the digital telemetry is limited to 80 bits/second (10 counts/second), an additional circuit is used which generates an analog signal proportional to the time from the end of one telemetry read cycle to the sensing of the first pulse with energy greater than 4.7 MeV. This allows the dead time correction of the data. Exclusive of housekeeping, the output consists of an 8-bit energy word, an analog voltage identifying the detector, and an analog voltage exponentially proportional to the count rate.

Five of the detectors had energy calibration sources in their field of view. The sources were  $^{208}\text{Po}$ , alpha energy 5.114 MeV. The count rate of these sources was approximately 0.1 counts/second. An additional energy calibration comes from a small amount of  $^{210}\text{Po}$  that was accidentally deposited on the detector surface during testing. This contamination was on all ten detectors in varying amounts. The worst case was approximately 0.047 counts/second and the best had an undetectable quantity at launch.

The spectrometer was turned on at 15:47 GMT, July 29, and remained on until 12:43 GMT, August 7, except for short periods during major burns, water and urine dumps. The spectrometer functioned as expected during this period except for occasional bursts of noise in two detectors.

### 3.0 RESULTS

An early examination of the data indicated that the amount of alpha activity observed was very small with no obviously high signal regions. Thus to increase sensitivity, the data were overlaid with the orbital period and examined within time intervals consistent with the field of view of the instrument on the lunar surface. The data examined to date were only post-LM descent to avoid any possible extra background due to the radioactive thermal generator attached to the LM. There are three distinct types of signals that can be searched for. First would be alpha particles detected at energies consistent with the decay of  $^{222}\text{Rn}$  and her daughter products. The ratio of intensities in the  $^{222}\text{Rn}$  line and the daughter product lines (except  $^{210}\text{Po}$ ) is predictable and provides a consistency check for any observed signal. Since the production of  $^{210}\text{Po}$  is held up by the 21 year half-life of  $^{210}\text{Pb}$ , the ratio of alpha particles from the decays of  $^{222}\text{Rn}$  and  $^{210}\text{Po}$  will depend on the time history of the radon evolution. The second type of signal that could be expected would be from  $^{220}\text{Rn}$  and her daughter products. Again, since the daughter products come to equilibrium with  $^{220}\text{Rn}$  within about 20 hours, the relative intensities of all the alpha lines can be reasonably predicted.

The third type of signal would be alphas from  $^{210}\text{Po}$  only. These events indicate radon evolution which has occurred days to years previously. The radon and all daughters (except  $^{210}\text{Po}$ ) have died out and only  $^{210}\text{Po}$  whose production is held up the 21 year half-life of  $^{210}\text{Pb}$  remains.

At this point in time the results of our analysis are preliminary. The results will eventually be more complete and precise so this paper is essentially a report of our current progress.

3.1  $^{222}\text{Rn}$

We have used two methods to look for an excess in the number of counts whose energies correspond to alpha particles from the decay of  $^{222}\text{Rn}$ . The first method is comparing the total number of counts obtained with the detector in a lunar orientation with that of a deep space orientation and restricting the comparison to the appropriate energy channels. The second method consists of examining the total energy spectrum in a lunar orientation and looking for an increase in those energy channels when alphas from  $^{222}\text{Rn}$  are expected as compared to a background level that is given by neighboring channels. In the absence of radon emanation essentially all counts are due to cosmic ray interactions and the spectrum is expected to be uniform and featureless. With the first method we find for the region  $40^\circ\text{E}$  to  $180^\circ$  an excess of  $(2.9 \pm 1.1) \times 10^{-3}$  counts/sec in our detector corresponding to a lunar rate of  $(1.32 \pm 0.50) \times 10^{-3}$  dis/cm<sup>2</sup>-sec. From the second method we find for the same region a rate of  $(0.92 \pm 0.25) \times 10^{-3}$  dis/cm<sup>2</sup>-sec. Thus on the basis of the statistical significance there is evidence for the existence of  $^{222}\text{Rn}$  over a large part of the Moon. However, pending a more thorough examination of systematic errors such as uncertainties in the precise energy calibration of the detectors and possible live time corrections, we present these values as an upper limit rather than a finite result.

3.2  $^{220}\text{Rn}$

The second method, as described above, is more powerful in the case of looking for an indication of  $^{220}\text{Rn}$ . No excess counts are observed in the energy region of  $^{220}\text{Rn}$  disintegration in an energy spectrum consisting of 20 hours of data taken over all the lunar surface. The  $3\sigma$  upper limit to the average decay rate of  $^{220}\text{Rn}$  is  $3.8 \times 10^{-4}$  decays/cm<sup>2</sup>-sec. This does not preclude the possibility of finding local concentrations of  $^{220}\text{Rn}$  that exceed this limit.

### 3.3 $^{210}\text{Po}$

The result of the analysis does provide some evidence for a non-uniform distribution of  $^{210}\text{Po}$  on the surface of the Moon. An example is the region of the Moon overflown by the CSM during revolution 18-33 of Apollo 15.

Our sensitivity for detecting lunar surface concentrations of  $^{210}\text{Po}$  was reduced by the fact that the detectors were slightly contaminated by an external source of  $^{210}\text{Po}$  during a calibration procedure. However, it is still possible to look for variations of the total count rate of  $^{210}\text{Po}$  with lunar longitude. The contamination level will be constant with position on the Moon so real changes in count rate in the appropriate energy range can be interpreted as a lunar component.

A lunar region is within the field of view of the instrument for a multiple number of orbits, the exact number of orbits depending on lunar latitude. Thus, to look for local concentrations we have combined data from a number of orbits by folding over the orbital period of the Apollo spacecraft. The folded data from revolutions 18-33 were grouped in bins of  $20^\circ$  of lunar longitude. The count rates in various energy bands of the spectrum were then examined as a function of lunar longitude. Because the amount of contamination varied from detector to detector, those five detectors with the least contamination were examined separately and provide most of the sensitivity.

For those five detectors the count rate from 5.1 to 5.5 MeV tended to be systematically higher in the region of  $40^\circ\text{E}$  to  $180^\circ$ . To increase the statistics all data from 32 consecutive hours were added together. Figure 1 shows the count rate in the region from 5.1 to 5.5 MeV as a function of longitude for revolutions 18-33. The data between  $40^\circ\text{E}$  and  $180^\circ$  which extends from the western edge of Mare Crisium to the Van de Graaf-Orlov region are systematically higher than that in other longitude bins. The average count rate between  $40^\circ\text{E}$  and  $180^\circ$  is  $0.072 \pm 0.002$  counts/sec and between  $0-40^\circ\text{E}$  plus  $180^\circ\text{W}-0^\circ\text{W}$  is  $0.062 \pm 0.001$  counts/sec. These average count rates are shown as dashed lines on the figure. The excess between  $40^\circ\text{E}$  and  $180^\circ$  corresponds to  $(4.6 \pm 1.4) \times 10^{-3}$  dis/cm<sup>2</sup>-sec.

8-18

To verify that this is a true lunar signal and not a systematic live-time variation, all the data outside this energy bin were treated in a similar fashion. The results are shown in Figure 2. These data do not show this variation. The count rate between  $40^{\circ}$  E and  $180^{\circ}$  W is  $0.070 \pm 0.002$ , and between  $0-40^{\circ}$  E plus  $180^{\circ}$  W- $0^{\circ}$  W it is  $0.073 \pm 0.001$  counts/sec. If the variation seen in Figure 1 were due to a live time variation, both of these energy bins should be affected identically. Since they are not, we conclude that the excess in Figure 1 is due to a true lunar signal. The energy spectra of the counts indicates that the excess is due to  $^{210}\text{Po}$  only.

8-19

#### 4.0 SUMMARY AND DISCUSSION

A partial analysis of Apollo 15 orbital data from the Alpha Particle Spectrometer indicates that a non-uniform concentration of  $^{210}\text{Po}$  is found on the surface of the Moon. For an area extending from west of Mare Crisium to the Van de Graaf-Orlov region we find an excess  $^{210}\text{Po}$  activity of  $(4.6 \pm 1.4) \times 10^{-3} \text{ dis/cm}^2\text{-sec}$ . This amount is approximately one-ninth of the value reported by Turkevich et al. (1970) for the Surveyor 5 landing site and about a factor of ten higher than the upper limit reported by Lindstrom et al. (1971) for a rock sample returned by Apollo 11.

Our value for the activity of  $^{222}\text{Rn}$ , the progenitor of  $^{210}\text{Po}$ , is at most  $10^{-3} \text{ dis/cm}^2\text{-sec}$ , about a factor of nine smaller than the quantity of  $^{222}\text{Rn}$  that would be in equilibrium with the observed amount of  $^{210}\text{Po}$ . This implies that the  $^{210}\text{Po}$  activity at the time of Apollo 15 was a result of increased radon emanation from the Moon within a time scale comparable to the 21 years required for  $^{222}\text{Rn}$  to decay to  $^{210}\text{Po}$ . Referring to Earth analogies this is suggestive of transient radon emanation from the Moon that would be promoted by transient lunar emission of more common volatiles or by volcanic activity.

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FIGURE CAPTIONS

Figure 1 Count rate of alpha particles with energy from 5.1 to 5.5 MeV for the five least contaminated detectors as a function of lunar longitude. This energy range includes  $^{210}\text{Po}$  a descendent of  $^{222}\text{Rn}$ . This includes all available data from revolution 18 - 33. The dashed lines indicate the average value of the count rate over two sections of longitude as indicated.

Figure 2 Count rate of alpha particles with energy from 4.7 to 5.1 or 5.5 to 9.0 MeV for the five least contaminated detectors as a function of lunar longitude. This includes all available data from revolutions 18 - 33. The dashed line indicates the average count rate.

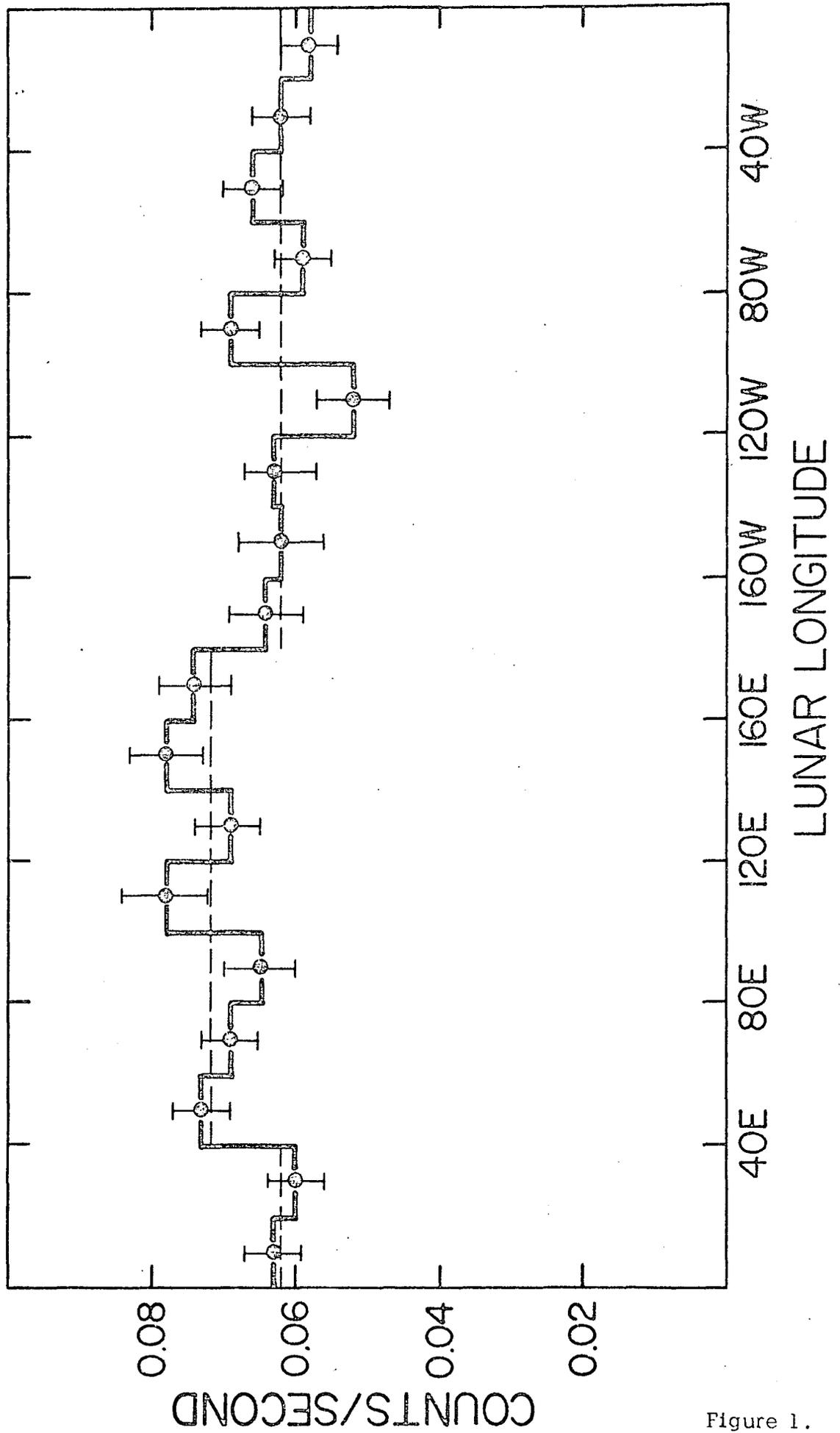
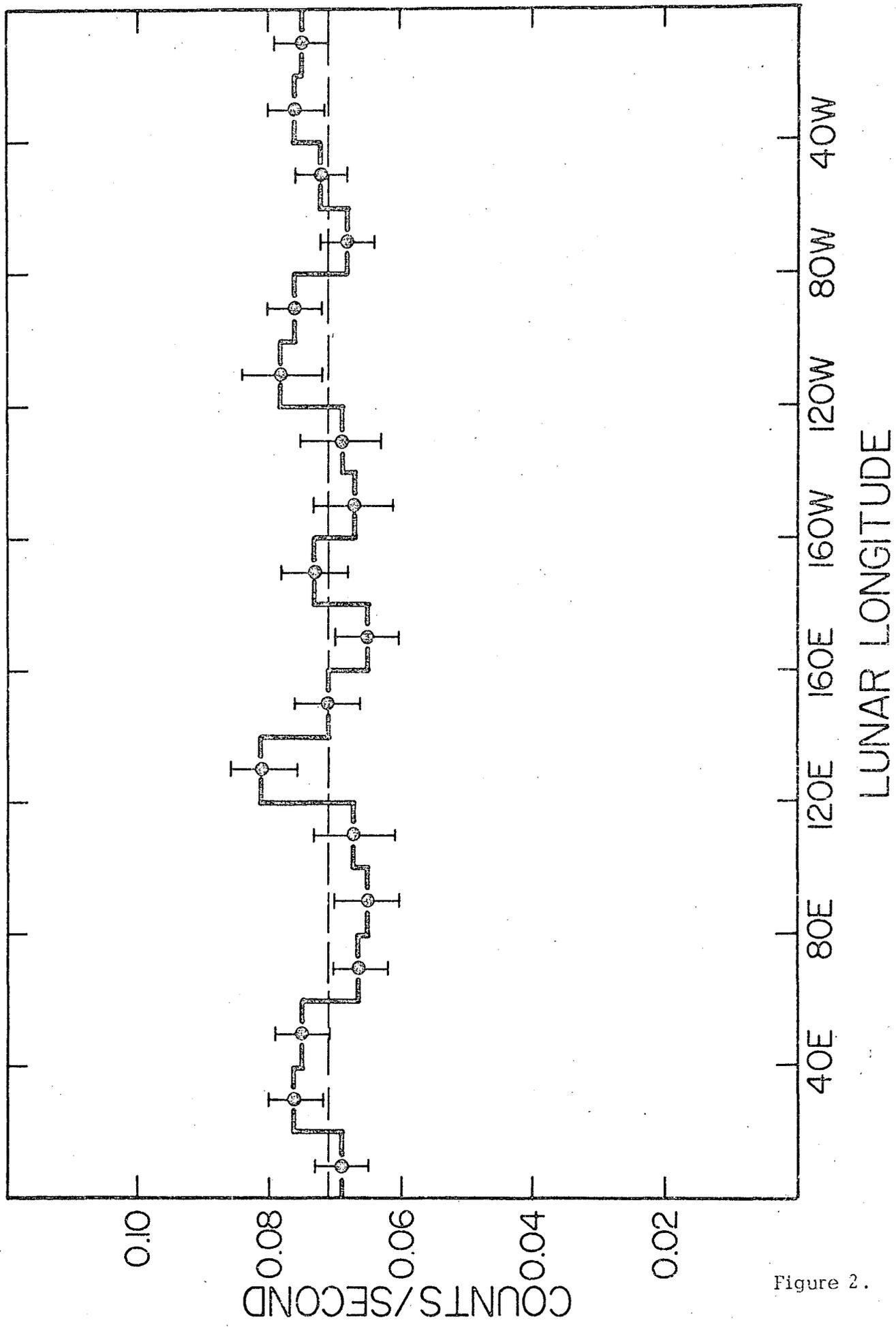


Figure 1.

8-23



2-P  
mix

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